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DEVELOPMENT OF ENGINEERING CRITERIA FOR USE OF SLURRY-TYPE EXPL--ETC(U)
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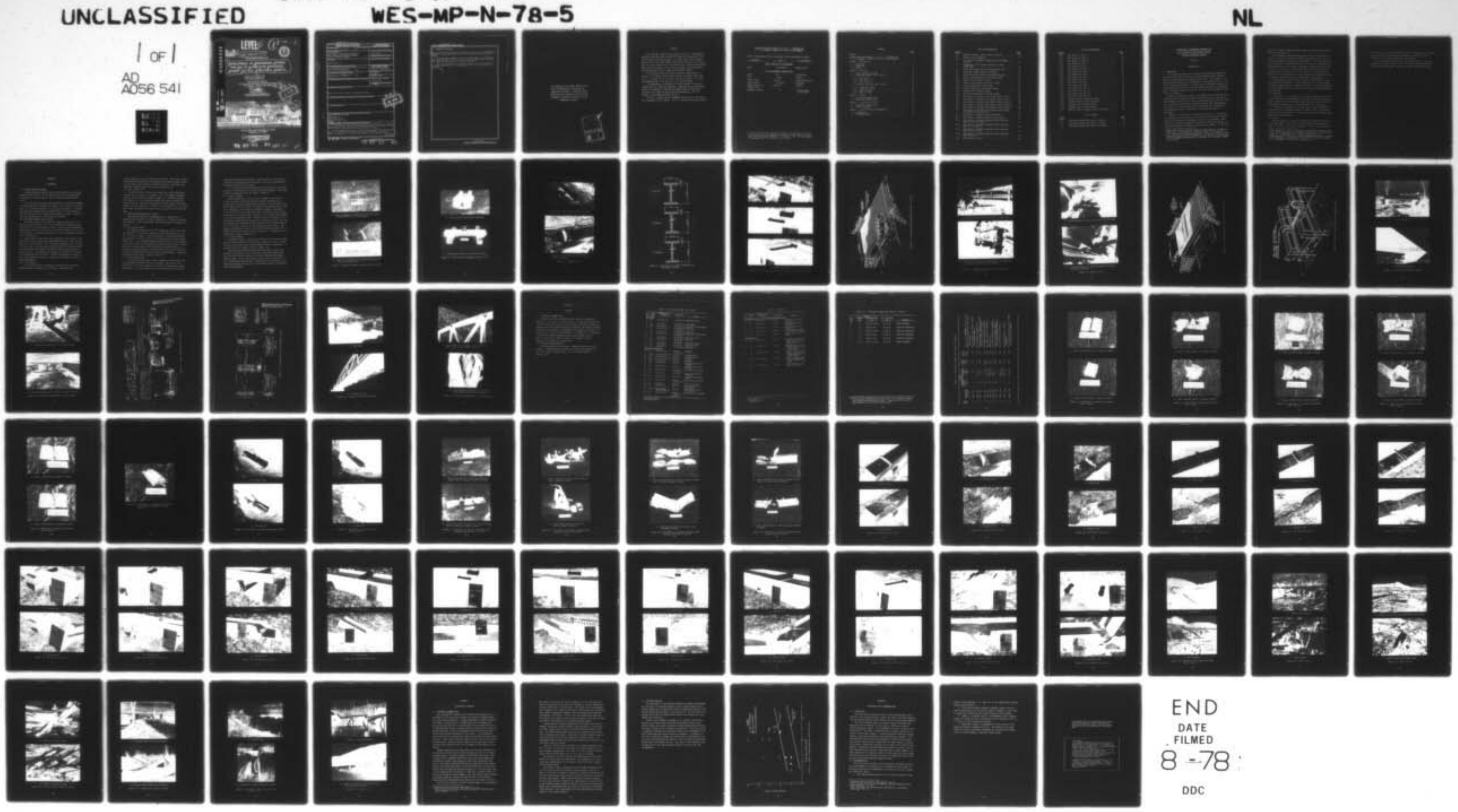

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DEVELOPMENT OF ENGINEERING CRITERIA FOR USE OF SLURRY-TYPE EXPLOSIVES AGAINST TACTICAL STRUCTURAL TARGETS.

by

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The objective of this study was to determine the effectiveness of a slurry-type explosive against common construction materials and to investigate the operational aspect of employing slurry against structural targets.

The investigation of slurry as a demolition charge was divided into two test phases. The first phase was conducted on structural elements. A total of 54 tests were conducted: 11 tests of steel plates 1/2, 1/4, 3/8, and 1 inch CONT

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thick; 27 tests of wide-flange steel beams; 11 tests of 12- and 16-inch-square reinforced concrete piers; and 5 tests of 12-inch-square wood (green oak) members.

The second phase consisted of four prototype bridges: two wide-flange steel stringer types, 40-foot clear spans; one reinforced concrete, 40-foot clear span; and one steel truss, 108-foot clear span.

Slurry was demonstrated to be effective against structural elements and prototype bridge structures. Recommendations for the use of slurries are presented.

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PREFACE

This study was conducted by personnel of the U. S. Army Engineer Waterways Experiment Station (WES), CE, under the sponsorship of the Office, Chief of Engineers (OCE), U. S. Army, under Program Element 62719A, Project No. 4A762719AT40, Task Area A1, Work Unit 012, and was under the staff supervision of the Directorate of Military Engineering. The study was in support of the overall program to develop Military Engineering Application of Commercial Explosives (MEACE).

The work was accomplished under the general supervision of Messrs. W. J. Flathau, Chief, Weapons Effects Laboratory (WEL), WES, and J. T. Ballard, Chief, Structures Division (SD), WEL. The report was prepared by Mr. J. M. Watt, Jr., SD, Project Manager.

The organization of laboratories at WES underwent a structural change since this study was completed. Organizations and individuals listed as incremental to WEL are now engaged under the Structures Laboratory (SL), WES, Mr. Bryant Mather, Acting Chief. Mr. W. J. Flathau is now Acting Assistant Chief, SL.

COL John L. Cannon, CE, was Commander and Director of WES during the preparation of this report. Mr. F. R. Brown was Technical Director.

CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to U. S. Customary		
grams	0.002204622	pounds (mass)
U. S. Customary to Metric (SI)		
inches	25.4	millimetres
feet	0.3048	metres
square inches	645.16	square millimetres
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	6894.757	pascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Use of gelled slurries has developed in the mining and quarrying industry because gelled slurries are cheap, extremely safe, pourable, water resistant, and have a high blast efficiency. The possibility of a cheaper and safer explosive is appealing to the military as well. It is for this reason that Report 1[1] was published, introducing the concept of using commercial explosives to satisfy military excavation requirements: barrier formation, target destruction, and large-scale excavation in the theater of operation.

Slurries are generally mixtures of inorganic nitrate oxidizers and carbonaceous fuels and may contain additional substances, such as powdered aluminum, ferrosilicon, and/or a high explosive such as TNT. Slurries contain high proportions of ammonium nitrate (AN) (approximately 80 percent) in an aqueous solution and, depending on the remainder of the ingredients, can be classified as either blasting agents or explosives.

Slurries are identified as nonideal explosives, i.e., the detonation properties are a function of the physical and chemical properties as well as the exterior environment in which it is detonated. There have been at least 25 variables identified that affect in some way the blasting performance of ammonium nitrate/fuel oil (ANFO).[2] It has been

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1 Briggs, MAJ Joseph, "Military Engineering Applications of Commercial Explosives: An Introduction," Technical Report E-73-2, May 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2 "Monsanto Blasting Products ANFO Manual, Its Explosive Properties and Field Performance Characteristics," September 1972, Monsanto Company, St. Louis, Mo.

shown that slurries, with their high proportion of AN, exhibit many of these same variables.[3,4]

Those variables that appear most significant in the application of slurry as a demolition charge are charge total weight, shape, booster size and arrangement, and degree of confinement. From a military operational standpoint, temperature and shelf life are also significant considerations in the use of slurry. Upon aging, commercial slurry explosives lose some of their effectiveness through gel deterioration and segregation of the slurry solids. They freeze at temperatures below about -20°F, losing fluidity and in some formulations losing the ability to sustain a stable detonation in a reasonable charge diameter.

The investigation herein does not attempt to quantify all factors influencing the performance of slurry explosives, but it does attempt to show its applicability as a demolition charge. In the investigation, a typical slurry is applied to typical targets under normal environmental conditions.

1.2 OBJECTIVES

The objective of this program is to establish engineering criteria for the efficient troop employment of slurry-type explosives (blasting agents) against tactical structural targets such as bridges; field fortifications; and petroleum, oil, and lubricants (POL) facilities.

The specific objectives of the study herein are to determine the effectiveness of a slurry-type explosive against common construction materials and to investigate the operational aspect of employing slurry against structural targets.

1.3 SCOPE

The investigation of slurry as a demolition charge was divided into two test phases. The first phase was conducted on structural elements. A total of 54 tests were conducted: 11 tests of steel plates

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[3] Dick, Richard A., "Factors in Selecting and Applying Commercial Explosives and Blasting Agents," Information Circular 8405, 1968, Bureau of Mines, U. S. Department of the Interior, Washington, D. C.

[4] Dick, Richard A., "The Impact of Blasting Agents and Slurries on Explosives Technology," Information Circular 8560, 1972, Bureau of Mines, U. S. Department of the Interior, Washington, D. C.

1/2-, 1/4-, 3/8-, and 1-inch thick; 27 tests of wide-flange steel beams; 11 tests of 12- and 16-inch-square reinforced concrete piers; and 5 tests of 12-inch-square wood (green oak) members.

The second phase consisted of four prototype bridges: two wide-flange steel stringer types, 40-foot clear spans; one reinforced concrete, 40-foot clear span; and one steel truss, 108-foot clear span.

CHAPTER 2

PROCEDURE

2.1 TYPICAL EXPLOSIVE SYSTEM

A charge design employing a slurry blasting agent as the primary explosive must include: (a) the blasting cap, (b) an appropriately sized booster of high explosive, and (c) the slurry blasting agent itself.

A J-2 electrical blasting cap (pentaerthritol tetranitrate (PETN), 14.5 grams) was used throughout this study. It is similar in explosive power to the military special No. 8 electrical blasting cap. Boosters were made from standard military composition-4 (C-4) high explosive, and the slurries used were commercially available products. Figure 2.1 shows the components for a typical explosive system.

2.2 STRUCTURAL ELEMENT TESTS, PHASE I

The charge setup for the structural elements consisted of a J-2 electrical cap, a booster of C-4, and a container of appropriate type and size for the desired weight of slurry. Specific test arrangements, along with the results of the tests, are listed in Tables 3.1, 3.2, and 3.3 of Chapter 3. A general description of the test arrangement follows.

2.2.1 Test Series I.

In this series, eleven tests were conducted on steel plates. The plates were 12 by 18 inches and simply supported with a clear span distance of 11 inches (Figure 2.2a). The plate thicknesses were 1/4, 3/8, 1/2, and 1 inch. Several shots varying the weight of slurry were made on each thickness to determine the minimum charge weight required to sever the plate. The length of the charge and the width of the plate to be severed were both 12 inches. Similar arrangements were made for 15 steel wide-flange sections, 11 concrete piers (Figures 2.2b and c), and 5 wood members.

2.2.2 Test Series II.

A second test series was conducted on prestress concrete piers having a concrete strength, f'_c, of 5000 psi. The piers were

16 by 16 inches in cross section and 20 feet long. Piers were oriented horizontally and supported on wood supports with slurry charges placed at clear span sections along the length of the pier. The slurry was contained in plastic bags for this series (Figure 2.2d).

2.2.3 Test Series III.

In a third series, 12 tests were conducted on steel wide-flange sections (W12 × 50, W24 × 49, and W36 × 194). The general dimensions of these three sections are shown in Figure 2.3. Polyvinyl chloride (PVC) pipe of 3-, 4-, and 6-inch-diameters were used to contain the slurry explosive. The slurry was placed in single, double, and triple (Figure 2.4) charge patterns. Boosters of C-4 weighing 1/3 to 1/2 pound were formed into wafers and placed in the slurry at the end of the PVC pipe.

2.3 PROTOTYPE STRUCTURE TESTS, PHASE II

Four bridges located in the Huntington, Va., area were to be inundated as the result of a newly constructed U. S. Army Corp of Engineer reservoir. These bridges were thus made available for demolition testing.

2.3.1 Tatmen Run Bridge.

The Tatmen Run Bridge had a 23-foot roadway by 40-foot clear span and consisted of a bituminous asphalt and wood deck supported on ten W21 × 68 steel stringers. Five 60-pound bags of slurry blasting agent were placed on the sides of five of the stringers and at their midspan (Figure 2.5). A 1-1/4-pound standard military block of C-4 was attached to the side of each of the commercially packaged plastic bags of slurry. The five C-4 charges were interconnected with detonation cord, a J-2 electrical cap was attached to the detonation cord, and the electrical cap was fired employing a 10-cap military blasting machine. Preparation of charges on the bridge is shown in Figure 2.6.

2.3.2 Coffee Run Bridge.

The Coffee Run Bridge had a 23-foot roadway by 40-foot clear span and consisted of nine W18 × 60 steel stringers. The deck was constructed of 2- by 4-inch timbers laid on edge and covered with bituminous asphalt. A 4- by 12-inch by 32-foot-long trough was filled with

720 pounds of slurry blasting agent. Three blocks of C-4 were interconnected with detonation cord and placed in the slurry approximately at quarter points along the trough.

A J-2 electrical cap was attached to the detonation cord, and the system was fired with the 10-cap military blasting machine. The bridge geometry and demolition plan are shown in Figure 2.7.

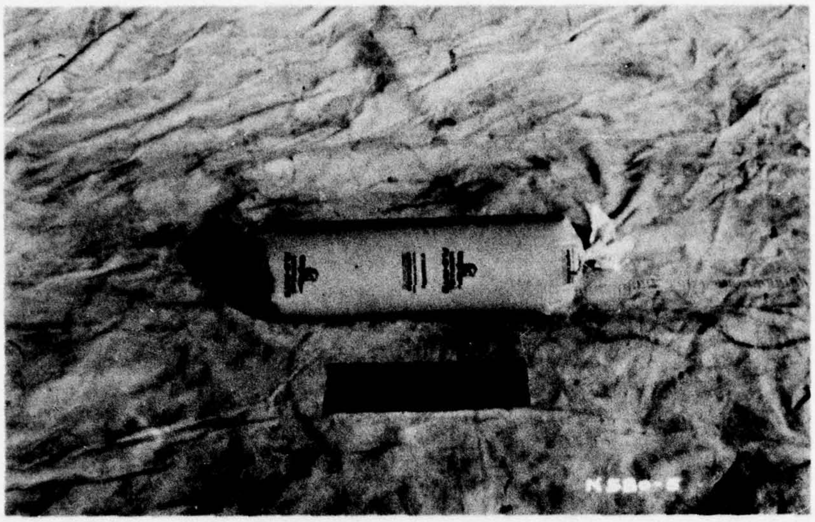
2.3.3 Sayer's Bridge.

Sayer's Bridge had a 16-foot, 6-inch roadway, a clear span of 40 feet, and was a reinforced-concrete structure consisting of a 14-1/2-inch slab poured integrally with side-rail concrete beams 20 by 45-1/2 inches in cross section. The amount of reinforcing steel could not be determined. The bridge was charged at midspan, employing a 3- by 4-inch by 16-foot trough filled with 120 pounds of slurry blasting agent and two 30-pound bags of slurry, one each placed at midheight of the concrete guardrail beam. One-half blocks (0.62 pounds) of C-4 were placed in each bag and two each in the trough of slurry. All four C-4 boosters were interconnected with detonation cord and detonated by one J-2 electrical cap and a 10-cap military blasting machine. The geometry and demolition plan of the bridge are shown in Figure 2.8. A preshot view of the bridge is shown in Figure 2.9. Preparation of the demolitions is shown in Figure 2.10.

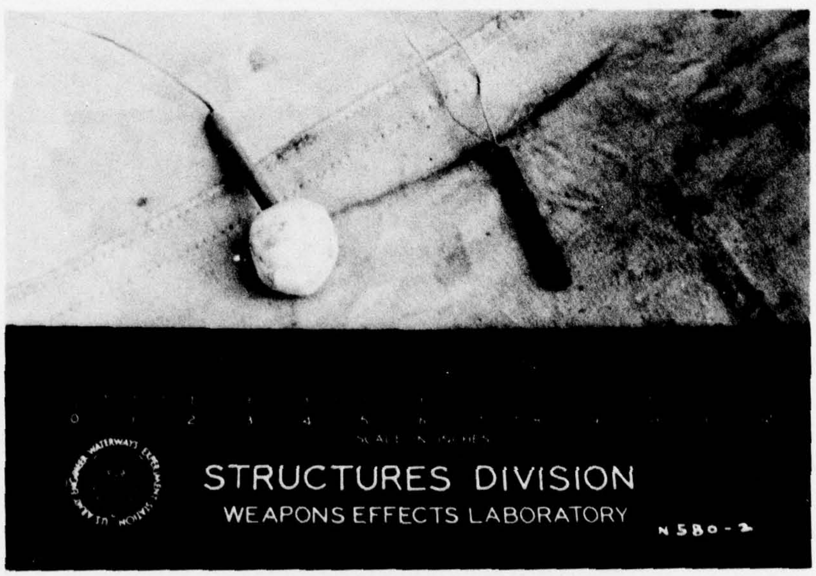
2.3.4 Trexler Bridge.

The Trexler Bridge, a steel truss structure, had a 14-foot roadway and two spans of 108 feet, 6 inches each. Figures 2.11 and 2.12 show the steel truss design, and pier and abutment design, respectively. A preshot view of the bridge is shown in Figure 2.13.

Each truss was charged with three 60-pound bags of slurry, two placed at the junction of the center panel compression member (Figure 2.14a) and one bag centered on the center panel tension member (Figure 2.14b). Each of the six bags was boosted with one stick of C-4. A detonation cord was used to interconnect the boosters, and the charge was detonated by use of a J-2 electrical cap and a 10-cap military blasting machine.

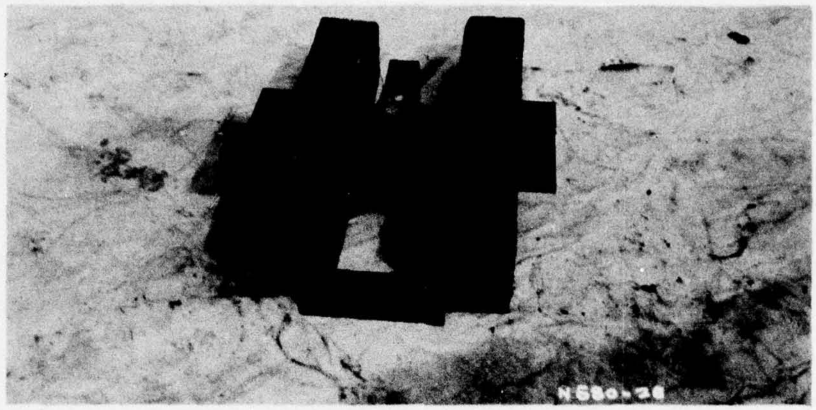


a. Typical package of commercially available slurry, (8-inch-diameter by 22-inch-length).

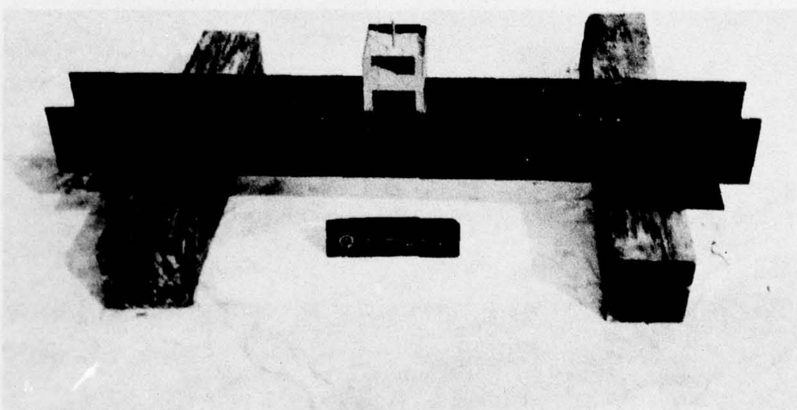


b. Ball of C-4 explosive with simulated cap and J-2 electrical blasting cap.

Figure 2.1 Explosive system, slurry, booster, and cap.



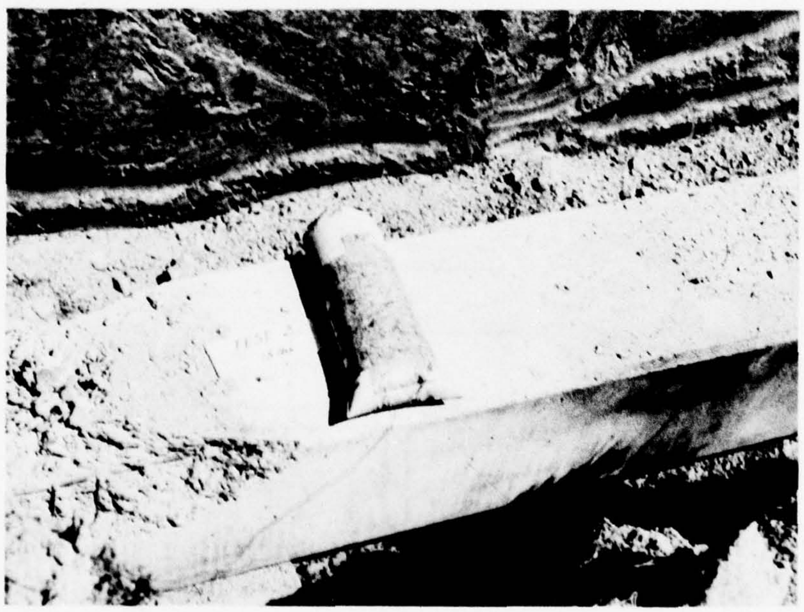
a. Steel plate with box charge containers.



b. Wide-flange beam with box charge containers.

Figure 2.2 Typical test arrangements (sheet 1 of 2).

c. Concrete column with box charge containers.



d. Concrete prestress piers with plastic bag charge containers.

Figure 2.2 (sheet 2 of 2).

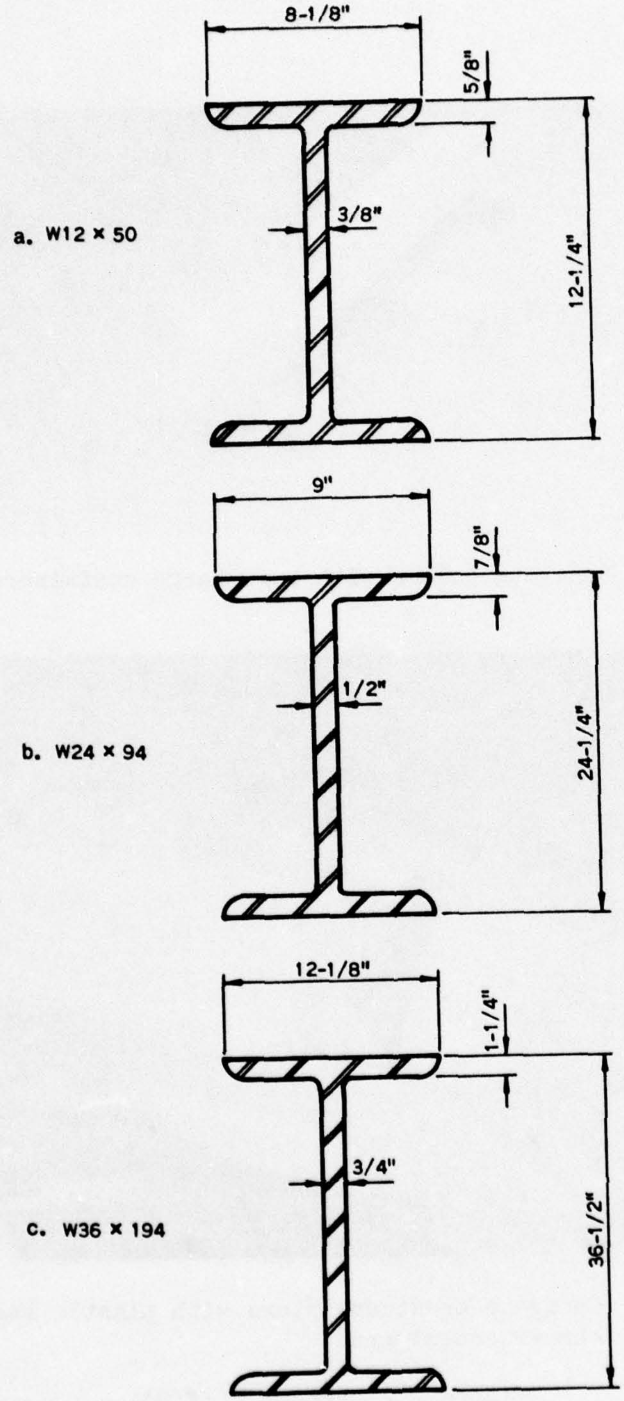
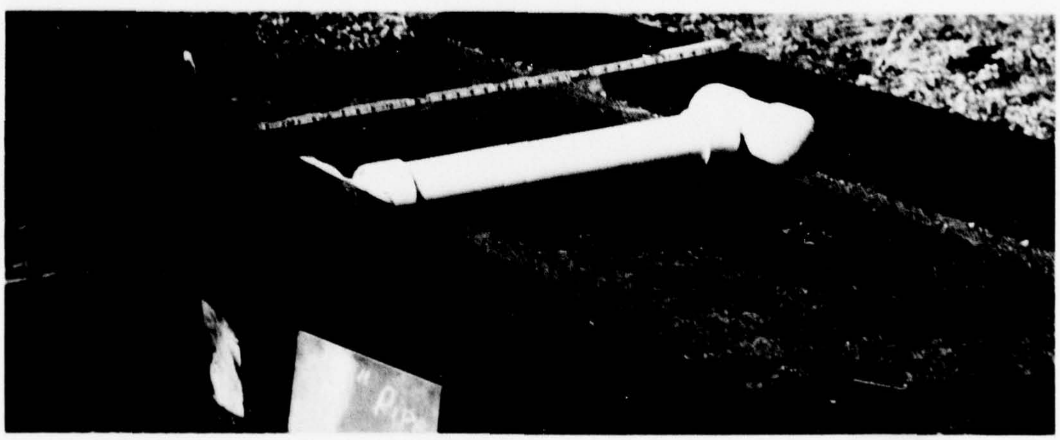


Figure 2.3 Test Series III general dimensions of wide-flange sections.

a. Single PVC pipe.

b. Double PVC pipe.



c. Triple PVC pipe.

Figure 2.4 Arrangement of PVC charge containers on wide-flange beams.

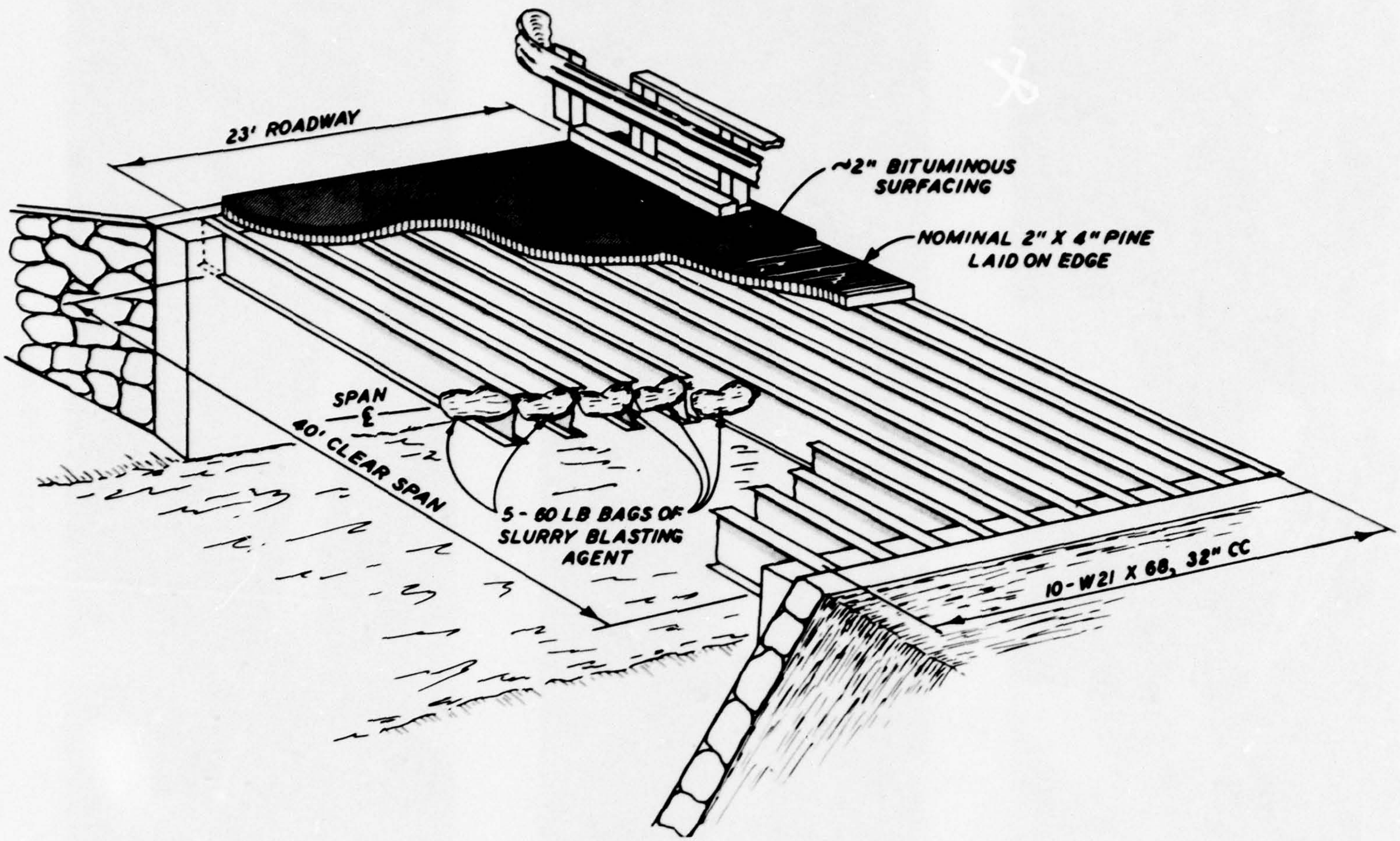
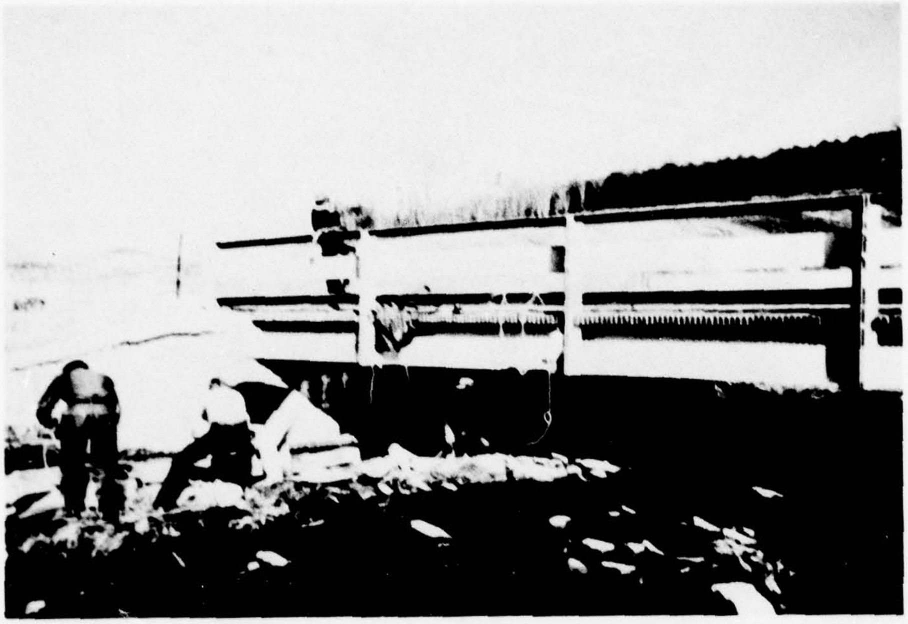


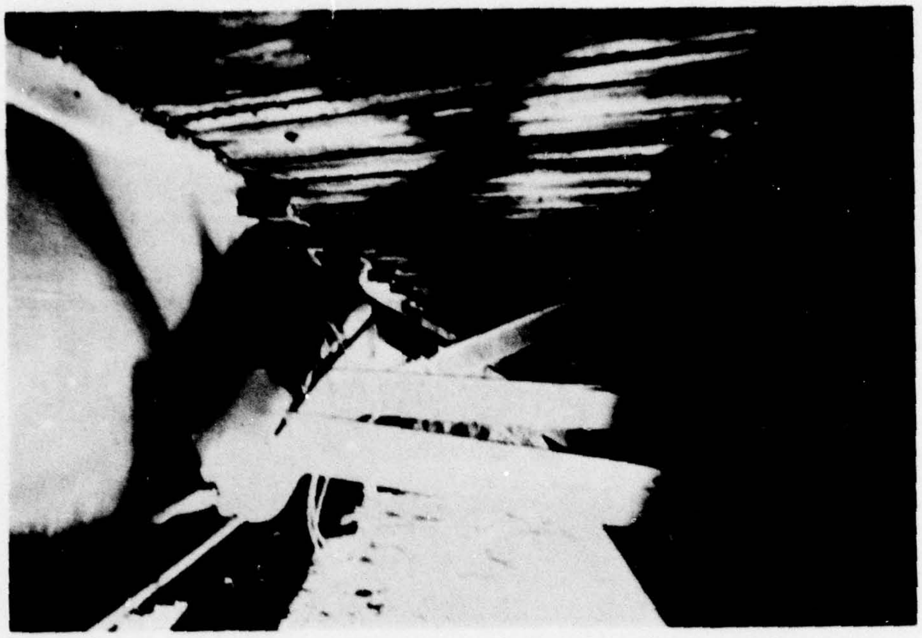
Figure 2.5 Tatmen Run Bridge geometry and demolition plan.



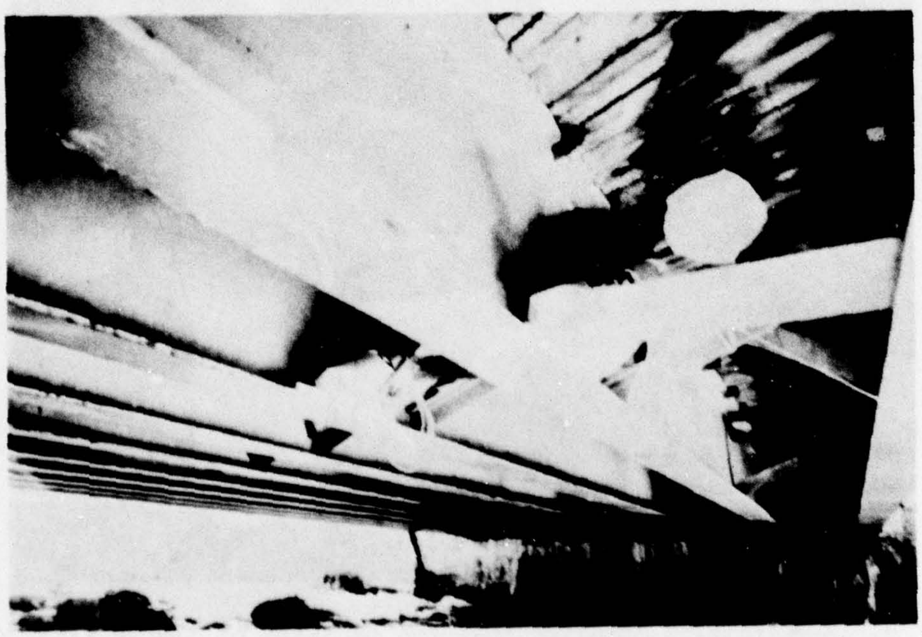
a. Slurry being prepared for placement on bridge beams.

b. Commercially obtained 60-pound packages of slurry with 1.25-pound C-4 block boosters attached.

Figure 2.6 Tatmen Run Bridge demolition operation (sheet 1 of 2).



c. 60-pound package of slurry positioned on bridge beam.



d. 60-pound packages of slurry positioned on skewed centerline of bridge.

Figure 2.6 (sheet 2 of 2).

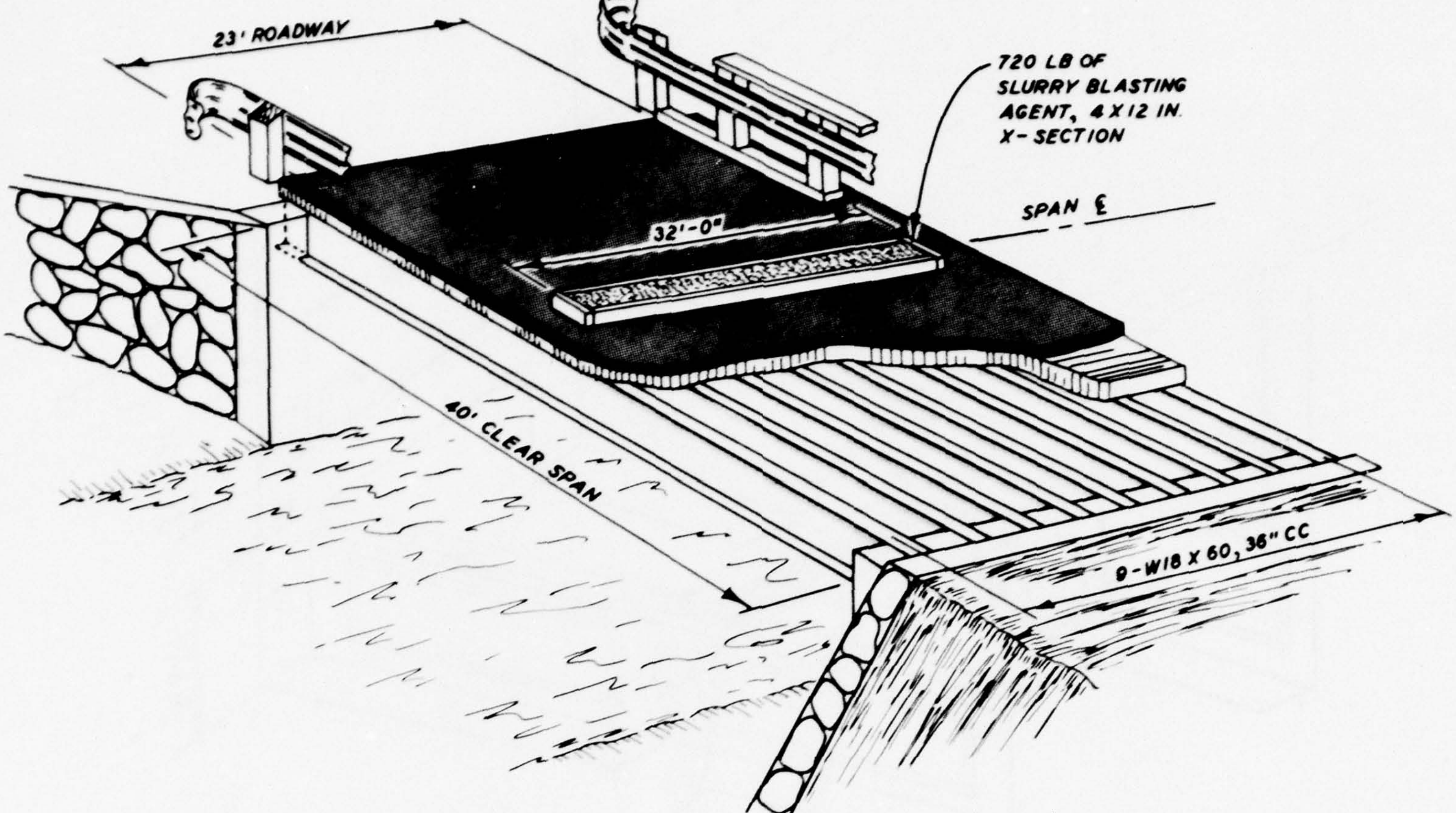


Figure 2.7 Coffee Run Bridge geometry and demolition plan.

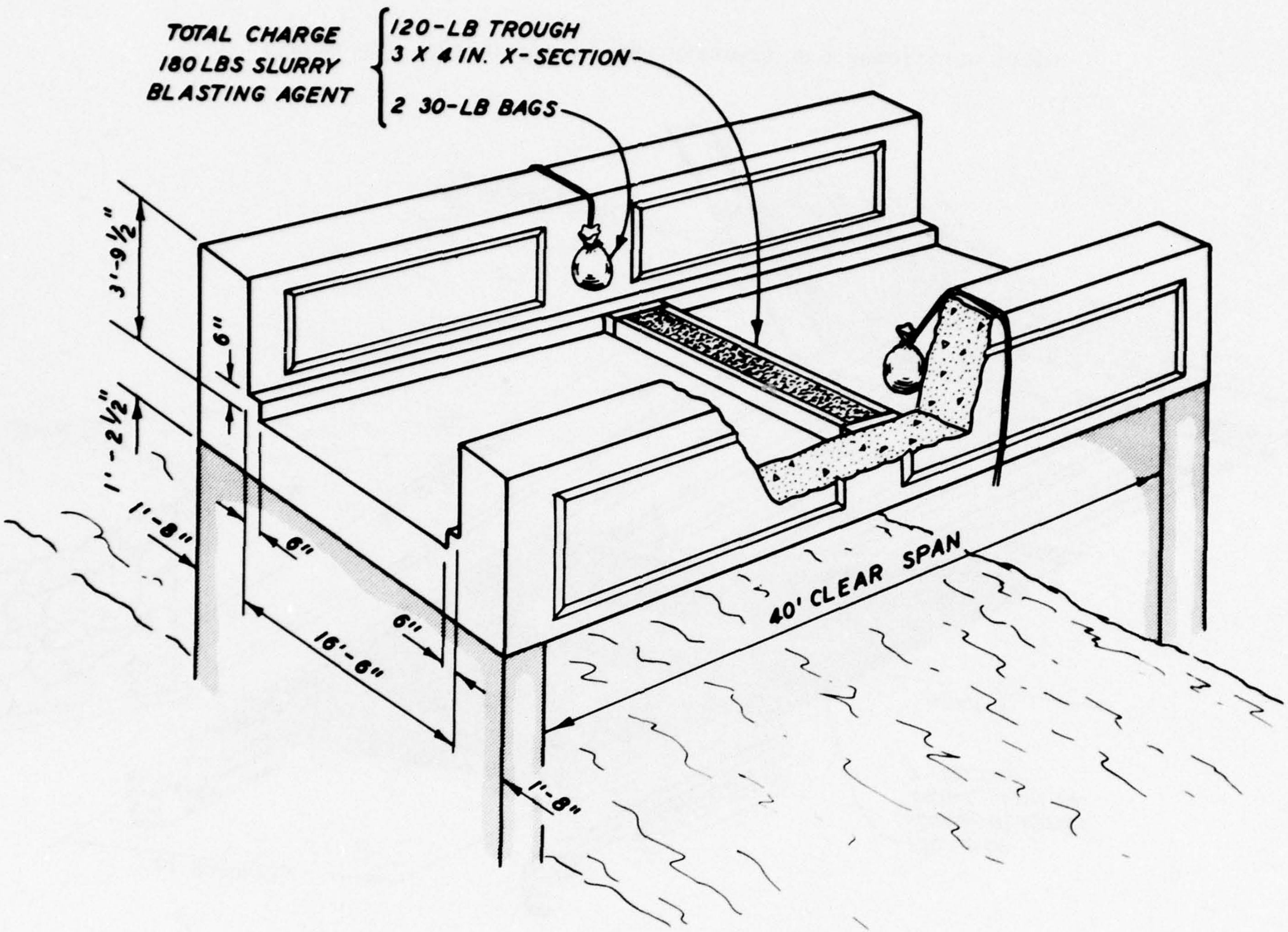
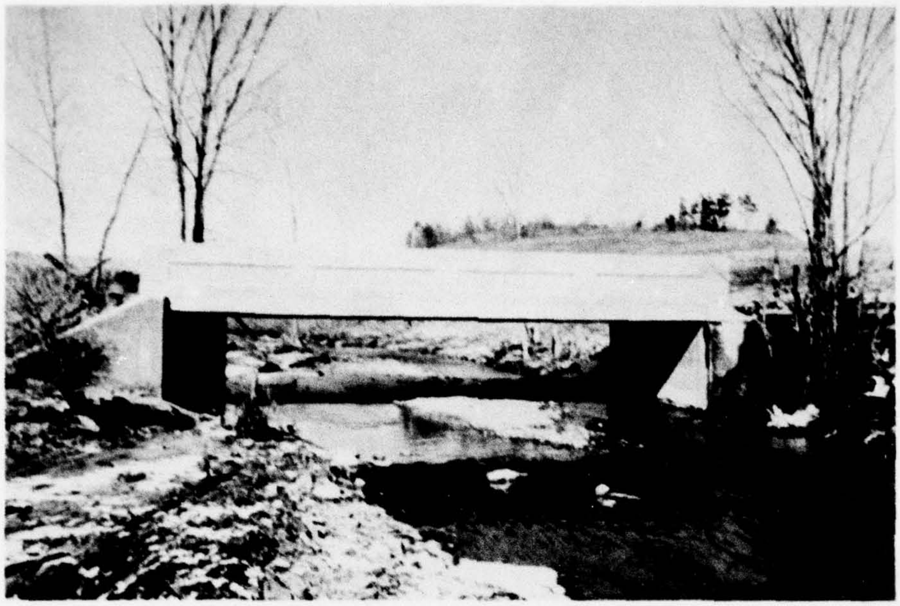
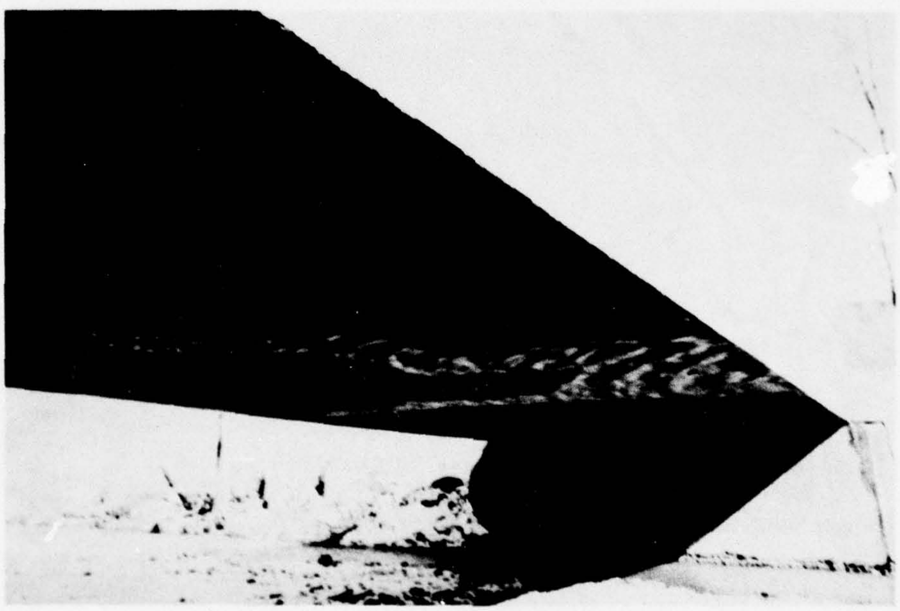


Figure 2.8 Sayer's Bridge geometry and demolition plan.



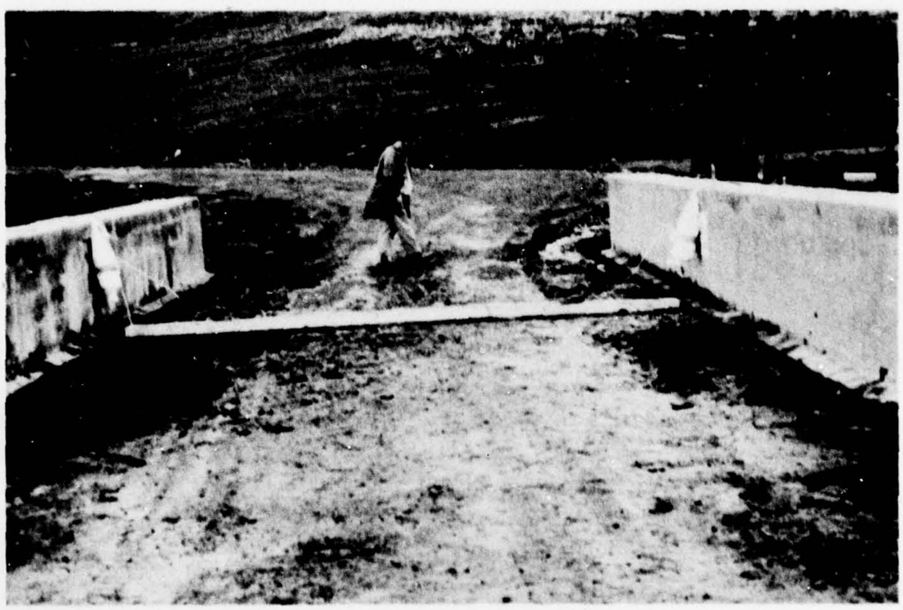
a. Side view.



b. Bridge, bottom side.

Figure 2.9 Preshot view of Sayer's Bridge.

a.- Slurry being poured into 3- by 4-inch trough.



b. Trough and 30-pound bag of slurry on bridge side beams.

Figure 2.10 Demolition preparation of Sayer's Bridge.

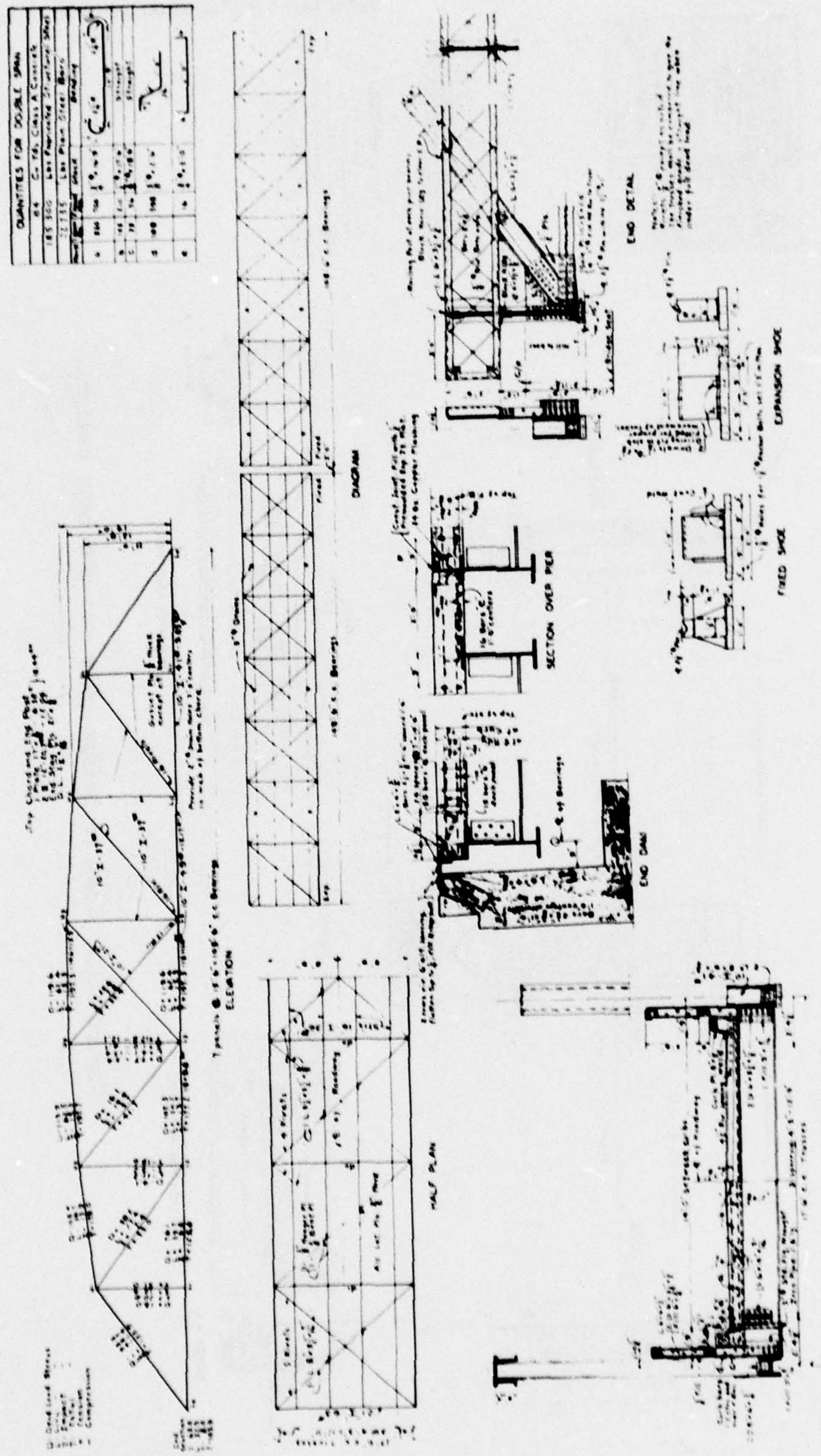


Figure 2.11 Trexler Bridge steel truss design.

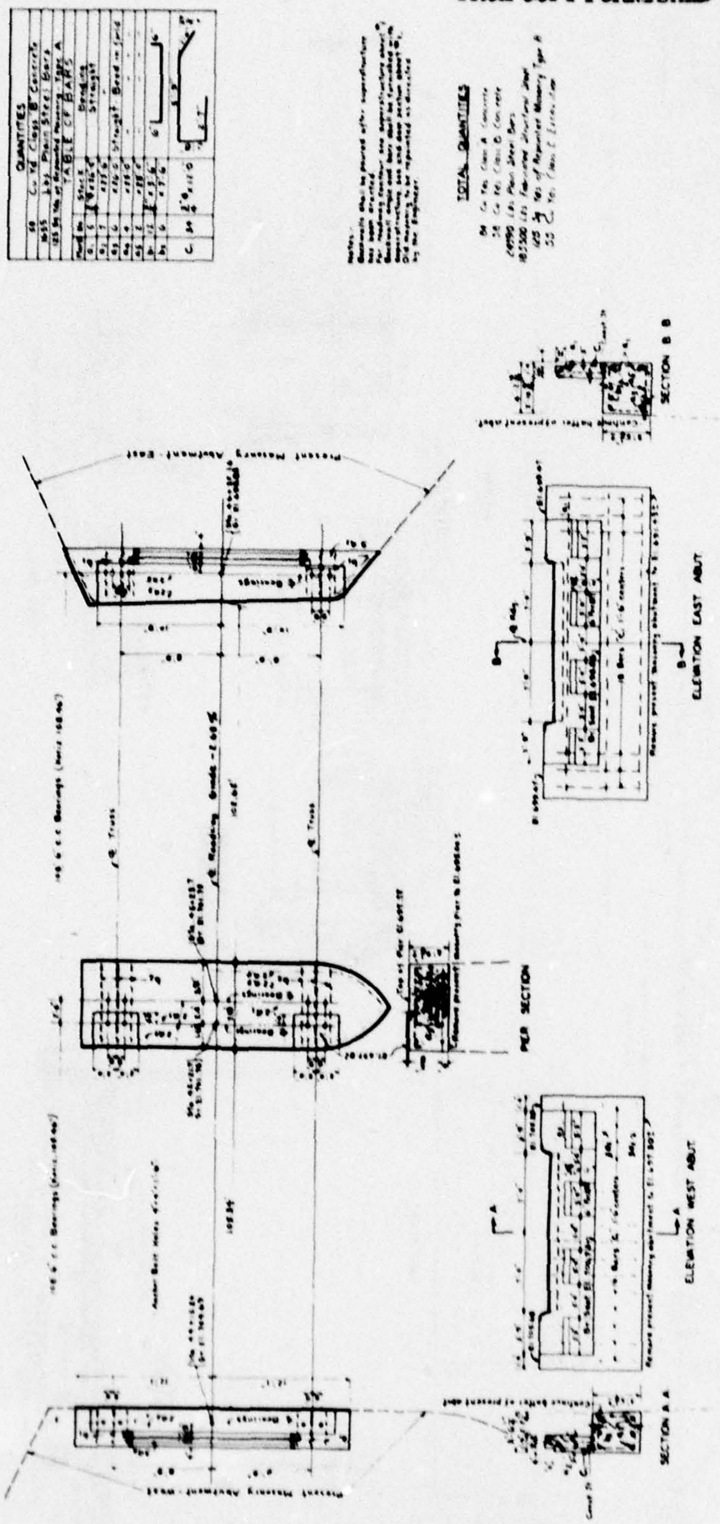
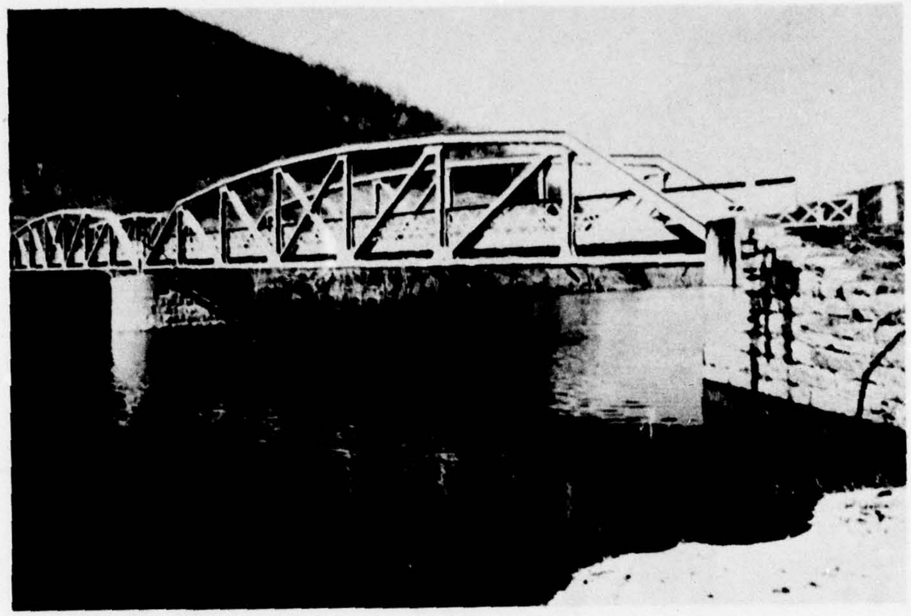
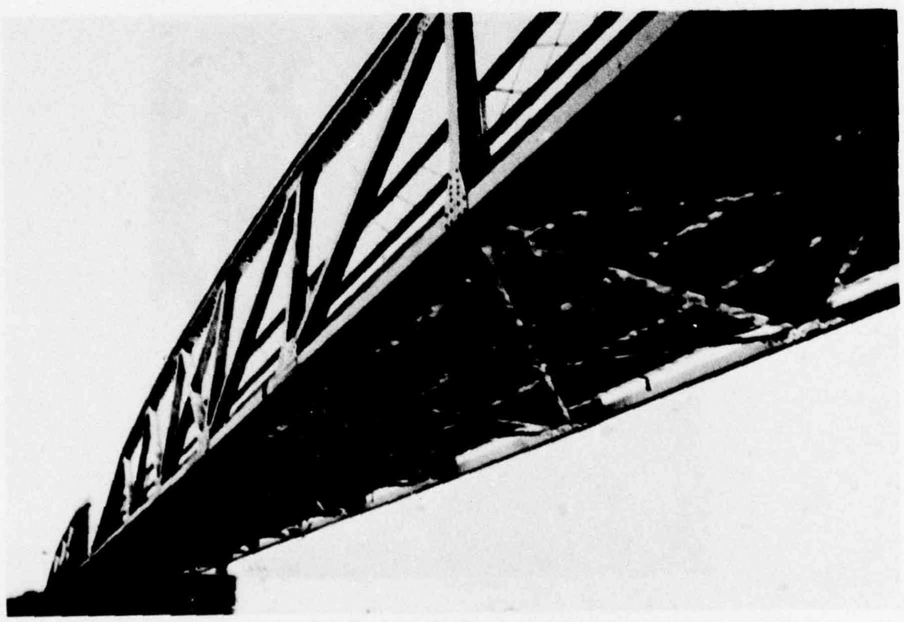


Figure 2.12 Trexler Bridge pier and abutment design.



a. Side view.



b. Bottom side view.

Figure 2.13 Preshot view of Trexler Bridge.

a. Two 60-pound bags of slurry to cut compression member (same on both bridge trusses).

b. One 60-pound bag of slurry to cut tension member (same on both bridge trusses).

Figure 2.14 Demolition preparation of Trexler Bridge.

CHAPTER 3

RESULTS

3.1 STRUCTURAL ELEMENT TESTS

The results of the structural element tests are presented in Tables 3.1, 3.2, and 3.3 for Test Series I, II, and III, respectively. Included in each table are the slurry charge configuration, weight of charge and booster, specimen tested, and comments concerning the damage incurred by the specimen. Photographs of the damage of specimens in Test Series I, are presented in Figures 3.1 through 3.12. Photographs of the preshot charge arrangement and postshot damage for Test Series II and III are shown in Figures 3.13 through 3.18 and Figures 3.19 through 3.29, respectively.

3.2 PROTOTYPE STRUCTURE TESTS

The photographs show the degree of damage incurred by the four bridges: Tatmen Run Bridge (Figure 3.30), Coffee Run Bridge (Figure 3.31), Sayer's Bridge (Figure 3.32), and Trexler Bridge (Figure 3.33).

Table 3.1. Structural element Test Series I results.

Test No.	Slurry Weight lb	Slurry Configuration in.	Test Specimen in.	Results
Steel Plates				
1	17.6	3 by 12 by 11.26	12 by 18 by 1/2	Broke plate in half.
2-5	--	--	--	--
6	5.0	3 by 12 by 3.2	12 by 18 by 1/2	Folded plate.
7	10.5	3 by 12 by 6.7	12 by 18 by 1/2	Broke plate into three pieces.
8	5.1	3 by 12 by 3.26	12 by 18 by 3/8 (4.5 sq in.)	Folded plate.
9	5.0	3 by 12 by 3.2	12 by 18 by 1/2	Folded plate.
10	5.0	3 by 12 by 3.2	12 by 18 by 1/4 (3.0 sq in.)	Broke plate into three pieces.
11	7.5	3 by 12 by 4.8	12 by 18 by 3/8	Broke plate in half.
12	10.0	3 by 12 by 6.4	12 by 18 by 1 (12 sq in.)	Plate bent.
13	15.0	3 by 12 by 9.6	12 by 18 by 1	Broke plate in half.
14	12.5	3 by 12 by 8.0	12 by 18 by 1	Broke plate in half.
15	7.5	3 by 12 by 4.8	12 by 18 by 1/2	Folded plate.
Structural Steel Sections				
16	12.1	3 by 8.75 by 10.6	S10 by 35 (10.3 sq in.)	No damage.[a]
17	2(8.75)	2 at (3 by 8.75 by 7.7)	S10 by 35	One flange bent.[a]
18	25.1	6 by 8.75 by 11.0	S10 by 35	Beam broke in half.
19	2(14.45)	2 at (5 by 8.5 by 7.8)	S10 by 35	No damage.[a]
20	21.0	8.5 dia by 8.5	S10 by 35	No damage.[a]
21	18.0	6 by 8.5 by 8.1	S10 by 35	Broke into two pieces with fragments.
22	15.1	6 by 8.5 by 6.8	S10 by 35	Broke into two pieces with fragments.
23	15.0	6 by 12.25 by 4.7	S15 by 42.9 (12.6 sq in.)	Tore out web and one flange.
24	15.0	6 by 13 by 4.4	S15 by 42.9	Tore into two halves plus fragments.
25[b]	15.0	6 by 13 by 4.4	S15 by 42.9	Tore out web and broke one flange.
26	11.6	6 by 8.5 by 5.2	W10 by 45 (13.2 sq in.)	Blew out web and one flange.
27	12.0	8 dia by 5.5	W10 by 45	Broke into two pieces.
28[b]	13.0	6 by 10 by 8.75	W10 by 45	Blew out web and half of both flanges.
29	2(5.75)	Opposing charges 2(3 by 4.5 by 8-3/4)	W10 by 45	Blew out web and half of both flanges.
30[b]	10.0	6 by 7.95 by 5.3	W8 by 40 (11.8 sq in.)	Broke into two pieces, ragged.

(Continued)

[a] Low-order detonation.
[b] Clear span, 35-1/2 in.

Table 3.1. (Concluded)

Test No.	Slurry Weight lb	Slurry Configuration in.	Test Specimen in.	Results
Concrete Sections[a] tested at 28 days, approximately 3000 psi				
31	14.5	6 by 12 by 4.6	12 by 12	Removed all concrete from charge area.
32	9.2	4 by 12 by 4.4	12 by 12	Removed all concrete from charge area.
33	4.7	4 by 12 by 2.3	12 by 12	Removed all concrete from charge area.
34	3.3	3 by 12 by 2.1	12 by 12	Fractured concrete severely; did not remove all concrete.
35[b]	4.8	3 by 12 by 3	12 by 12	Removed concrete in charge area.
Oak Wood Sections[c]				
42	3.25	3 by 12 by 2.1	12 by 12	Splintering of top and bottom sides of beam, no set in beam; top splintered to a depth of 4 in.
43	6.0	4 by 12 by 2.9	12 by 12	Same beam as Test 42, charge placed at 1/4 point; top splinter depth of 6 in., no flexural damage.
44	8.0	4 by 12 by 3.84	12 by 12	Charge at 1/4 point; seven inches crater depth; longitudinal splintering; some flexural bending.
45	12.0	4 by 12 by 5.8	12 by 12	Charge at midspan; cratered and split longitudinally, but did not sever all four pieces.
46	20.0	4 by 12 by 9.6	12 by 12	Charge at midspan. Broke beam into two pieces.

[a] Clear span, 35-1/2 in.
[b] Clear span, 79 in.
[c] Clear span, 86 in.

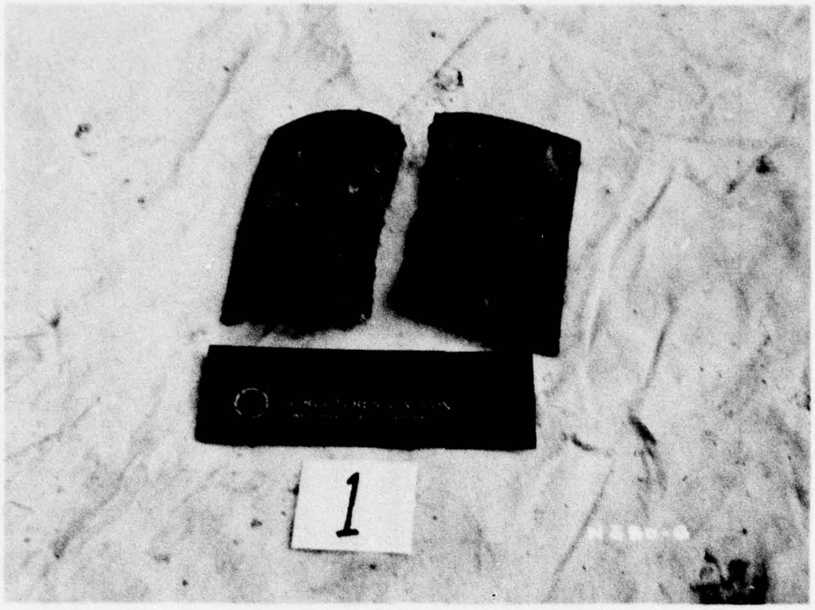
Table 3.2. Structural element Test Series II results.

Test No.	Slurry Weight lb	Slurry Configuration in.	Test Specimen in.	Results
1[a]	4	18 by 2.6 dia	16 by 16	Minor breakage.
2	15	18 by 5 dia	16 by 16	Cratered completely.
3	8	18 by 2.2 dia	16 by 16	Cratered completely.
4	5.5	18 by 2 dia	16 by 16	Cratered (minimum).
5	5.5	18 by 2 dia	16 by 16	Cratered (minimum).
6	3.5	18 by 1.5 dia	16 by 16	Minor breakage.

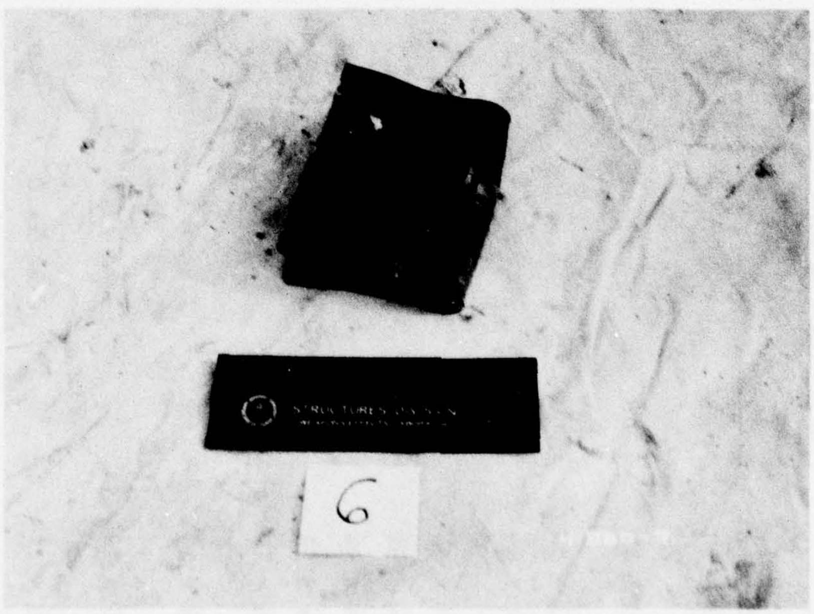
[a] Concrete piers (prestressed) 16- by 16-in., f'_c = 5000-psi concrete slurry ANOGEL manufactured by Trojan. Boosted with 1/4 lb of C-4 high explosive, J-2 electrical blasting cap.

Table 3.3. Structural element Test Series III results.

Test No.	Beam Size	Charge Configuration Pipe Diameter in.	Charge Configuration Pipe Length in.	Slurry Weight lb	C-4 Booster lb	Results
1	W12 × 50	3	9.5	4.5	0.30	Failed to cut flange on side, opposite charge.
2	W12 × 50	4	9.5	6.0	0.30	Cut all except one flange; boosted end maximum damage.
3	W12 × 50	4	2 at 4.5	4.5	0.62	No photograph, complete cut.
4	W24 × 94	4	21.0	14.5	0.30	Opposite flanges remained; charge placed to near end of beam.
5	W24 × 94	6	21.0	29.5	0.62	One opposite flange remained.
6	W24 × 94	4	2 at 11.0	16.0	0.62	One charge failed to detonate.
7	W24 × 94	3	2 at 11.0	9.0	0.62	Complete cut.
8	W24 × 94	3	2 at 5.0	4.5	0.62	One charge failed to detonate.
9	W36 × 194	6	32	42.5	0.62	(Booster end maximum damage.) One opposite flange remained.
10	W36 × 194	3	2 at 8 1 at 21.25	16.0	0.93	One end failed to initiate.
11	W36 × 194	3	2 at 11.0	9.0	0.62	One charge failed to perform completely.
12	W36 × 194	4	2 at 11.0	16.0	0.62	3 to 4 in. of steel not cut at center of web and at one flange.

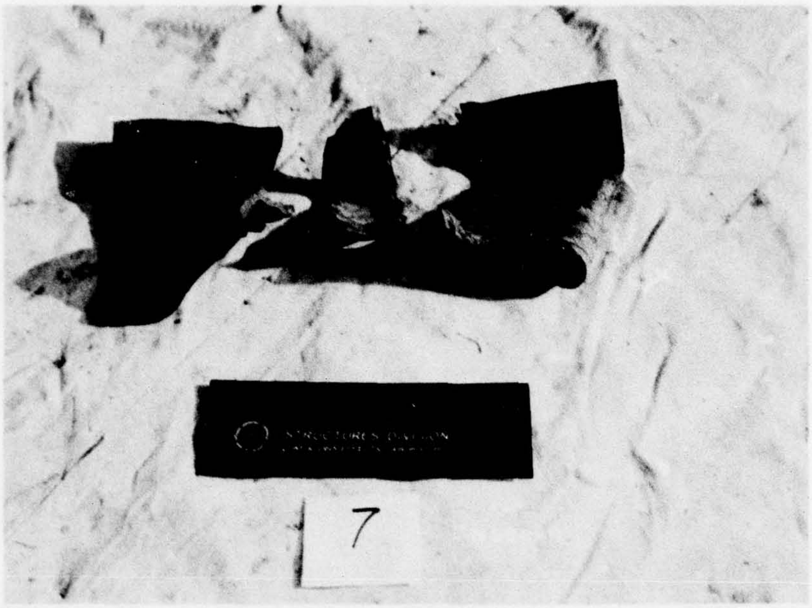


a. Plate, 1/2-inch thick, 17.6 pounds of slurry.

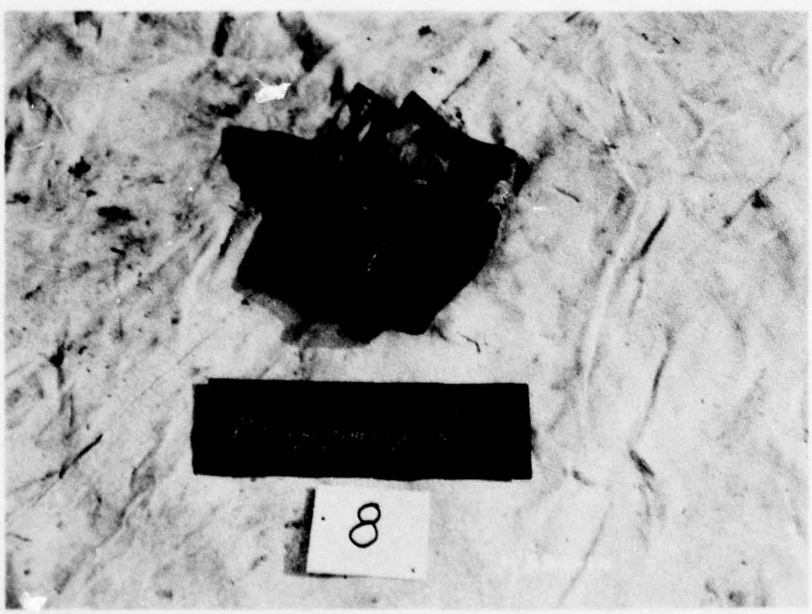


b. Plate, 1/2-inch thick, 5 pounds of slurry.

Figure 3.1 Test Series I, postshot steel plates, Tests 1 and 6.

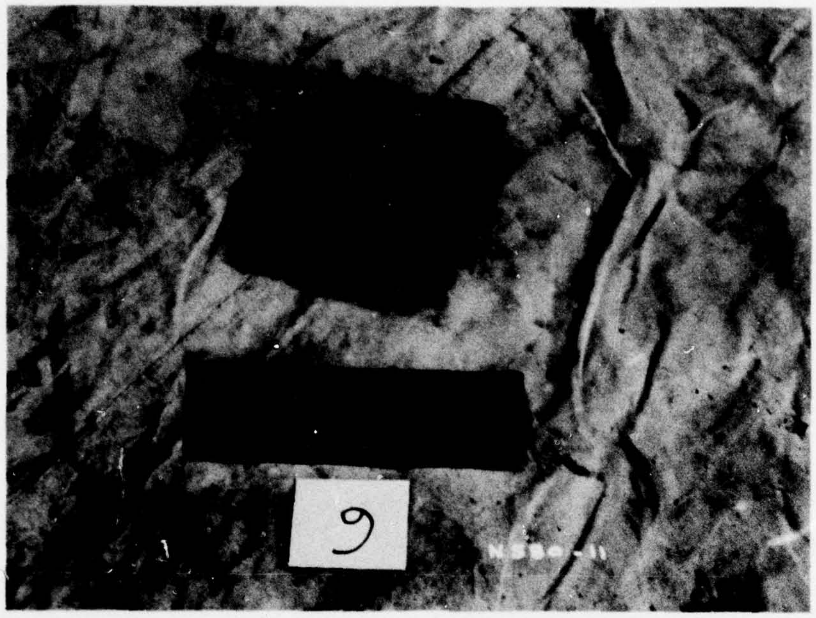


a. Plate, 1/2-inch thick, 10.5 pounds of slurry.

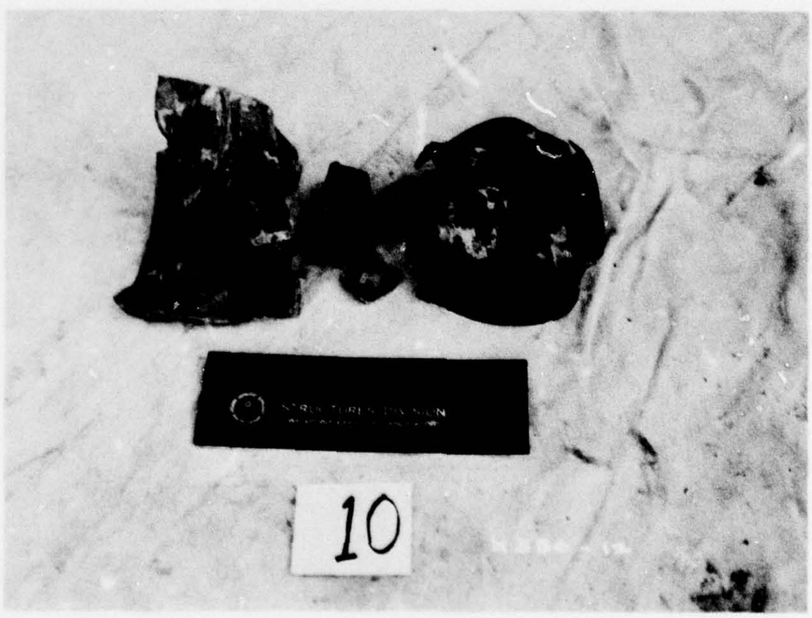


b. Plate, 3/8-inch thick, 5.1 pounds of slurry.

Figure 3.2 Test Series I, postshot steel plates, Tests 7 and 8.

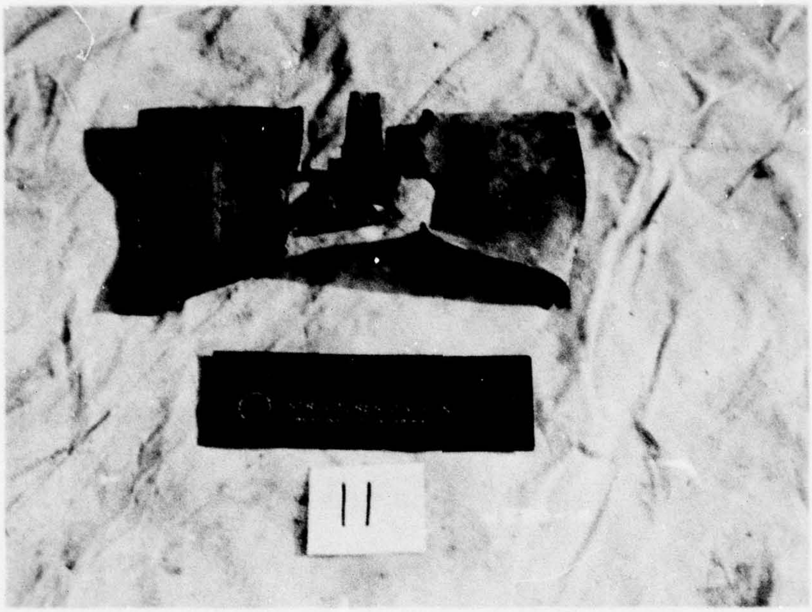


a. Plate, 1/2-inch thick, 5 pounds of slurry.

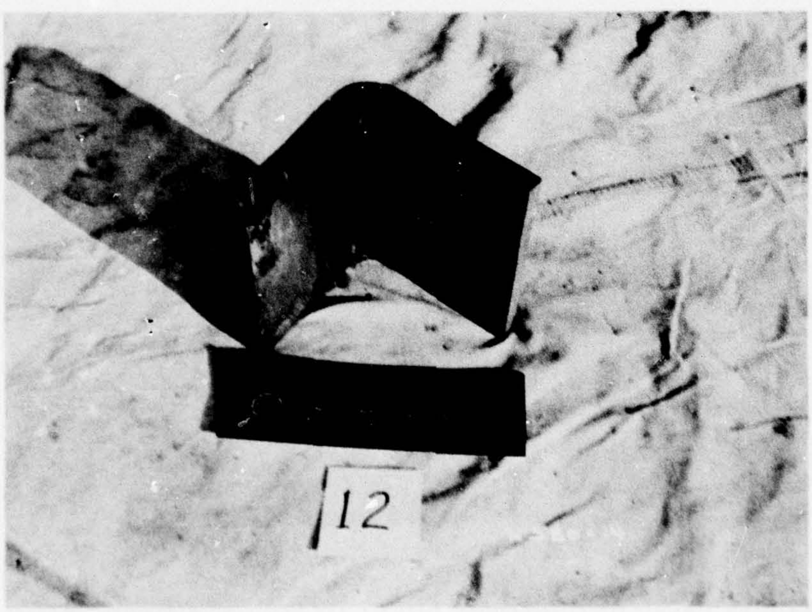


b. Plate, 1/4-inch thick, 5 pounds of slurry.

Figure 3.3 Test Series I, postshot steel plates,
Tests 9 and 10.

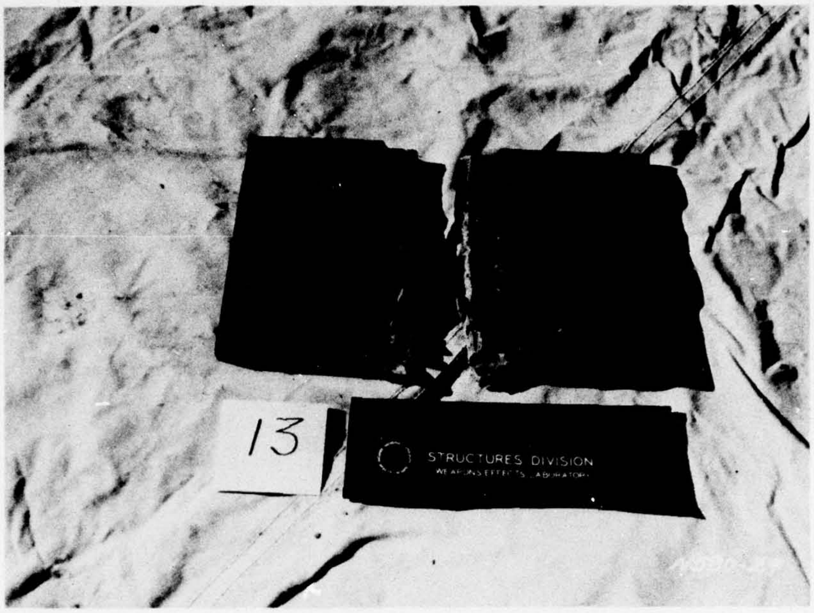


a. Plate, 3/8-inch thick, 7.5 pounds of slurry.

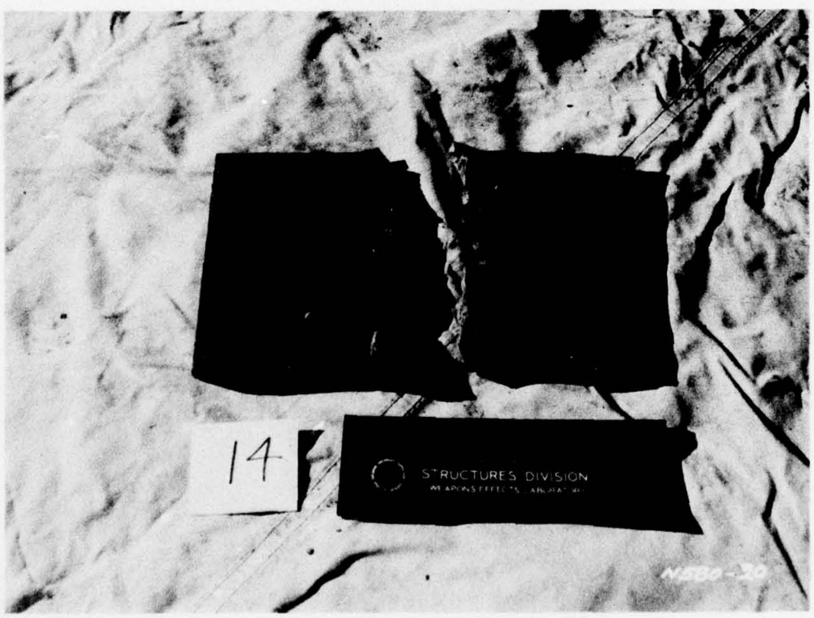


b. Plate, 1-inch thick, 10 pounds of slurry.

Figure 3.4 Test Series I, postshot steel plates, Tests 11 and 12.



a. Plate, 1-inch thick, 15 pounds of slurry.



b. Plate, 1-inch thick, 12.5 pounds of slurry.

Figure 3.5 Test Series I, postshot steel plates.
Tests 13 and 14.

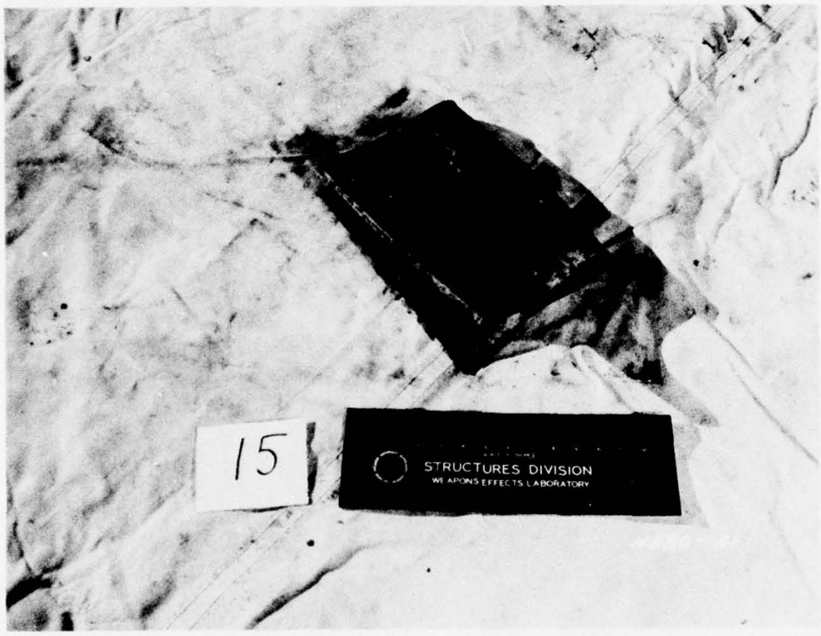
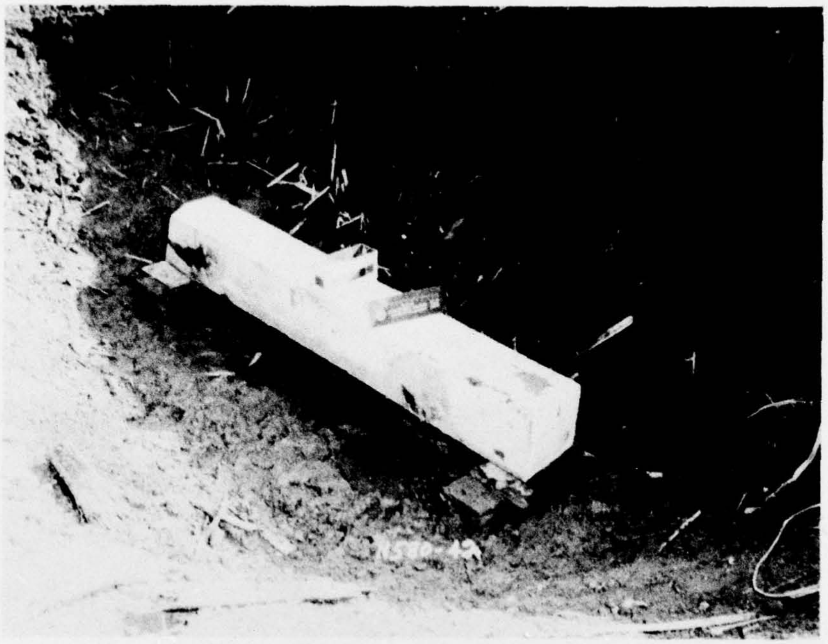


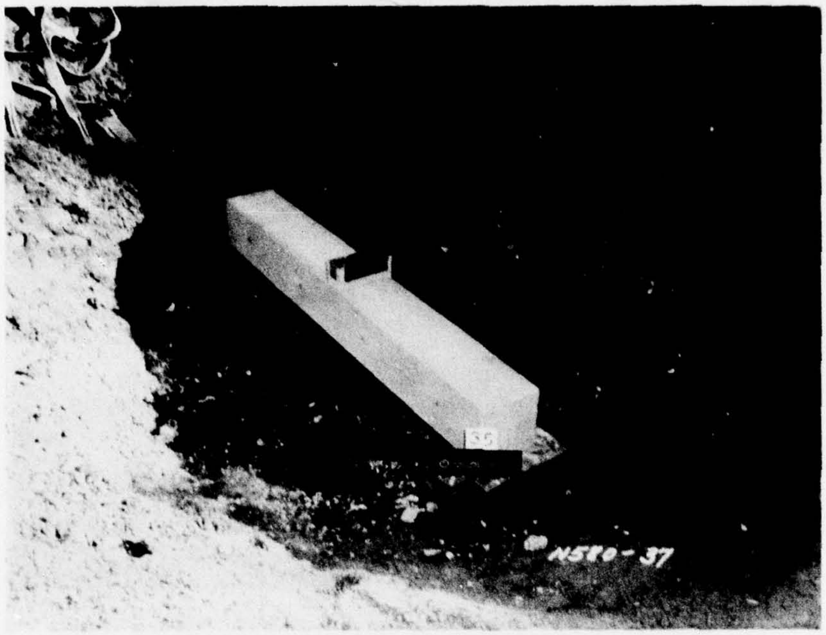
Figure 3.6 Test Series I, postshot 1/2-inch-thick steel plate, 7.5 pounds of slurry, Test 15.



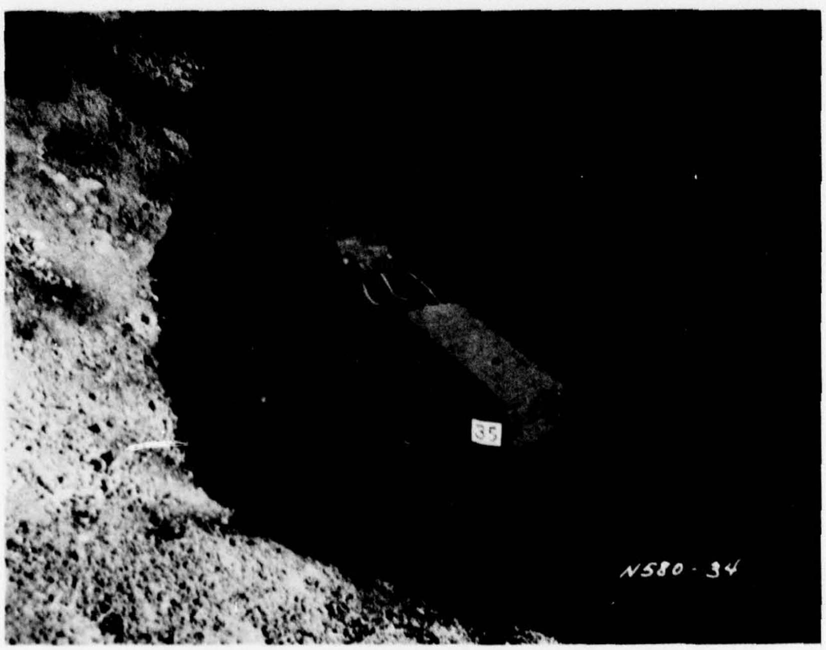
a. Preshot view.

b. Postshot view.

Figure 3.7 Test Series I, typical timber beam results.

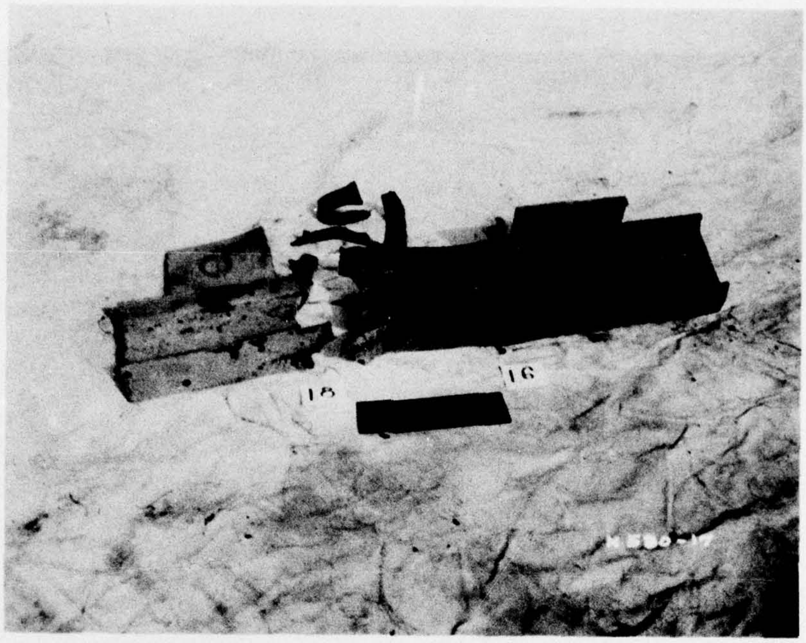


a. Preshot view.

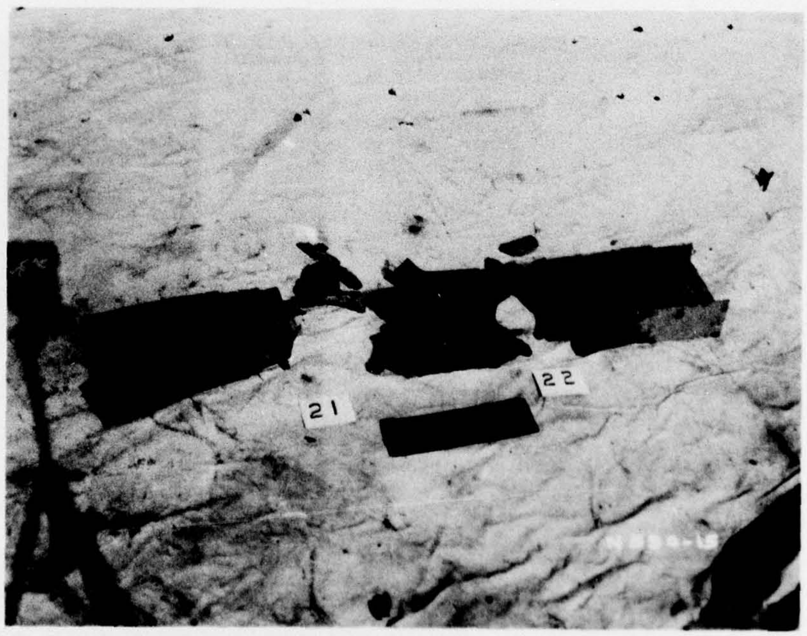


b. Postshot view.

Figure 3.8 Test Series I, typical concrete column results.



a. Steel section S10 by 35, Test 16, using 12.1 pounds; Test 18, using 25.1 pounds of slurry.



b. Steel section S10 by 35, Test 21, using 18 pounds; Test 22, using 15.1 pounds of slurry.

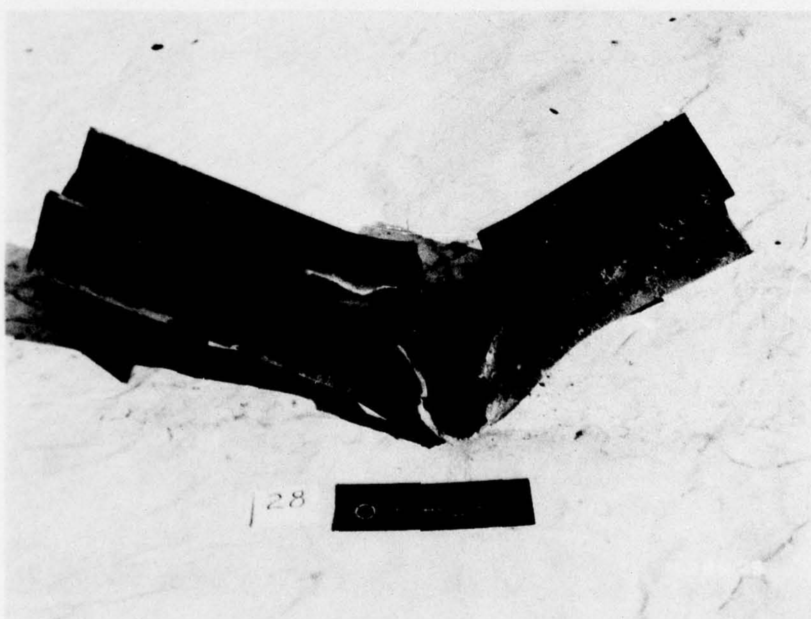
Figure 3.9 Test Series I, postshot structural steel sections, Tests 16, 18, 21, and 22.

a. Steel section S15 by 42.9, Tests 23 and 24, using 15 pounds of slurry.

b. Steel section S15 by 42.9, Test 25, using 15 pounds of slurry.

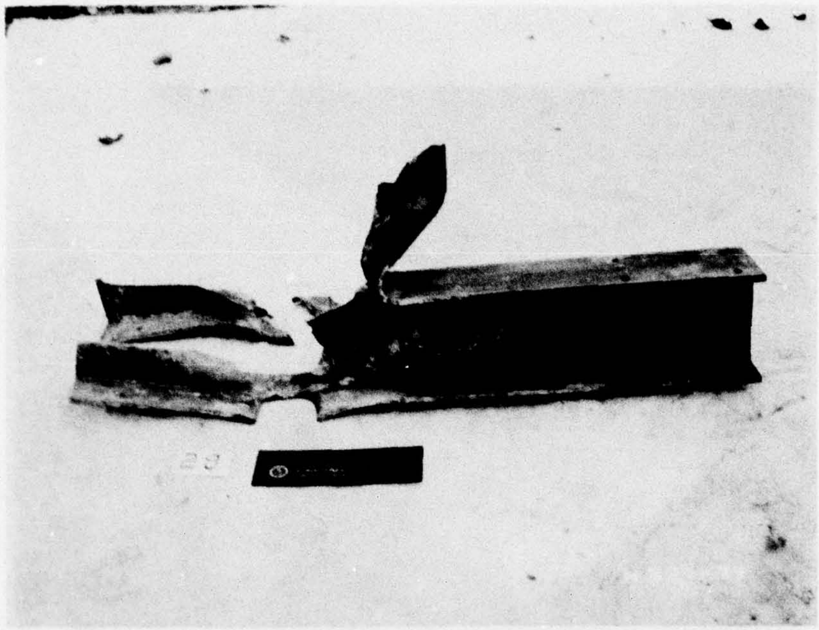
Figure 3.10 Test Series I, postshot structural steel sections, Tests 23, 24, and 25.

a. Steel section W10 by 45, Test 26, using 11.6 pounds; Test 27, using 12 pounds of slurry.

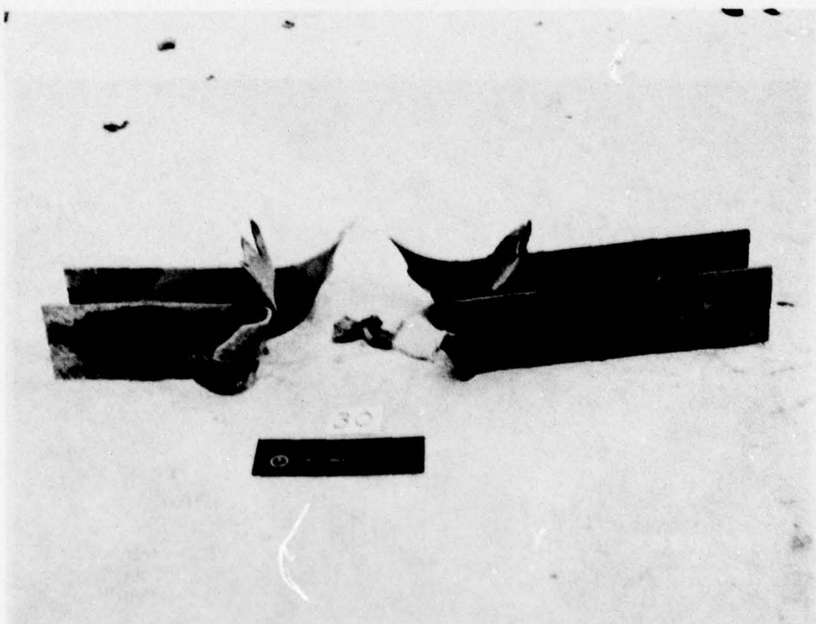


b. Steel section W10 by 45, Test 28, using 13 pounds of slurry.

Figure 3.11 Test Series I, postshot structural steel sections, Tests 26, 27, and 28.



a. Steel section W10 by 45, Test 29, using 2(5.75) pounds of slurry (opposing charge).



b. Steel section W8 by 40, Test 30, using 10 pounds of slurry.

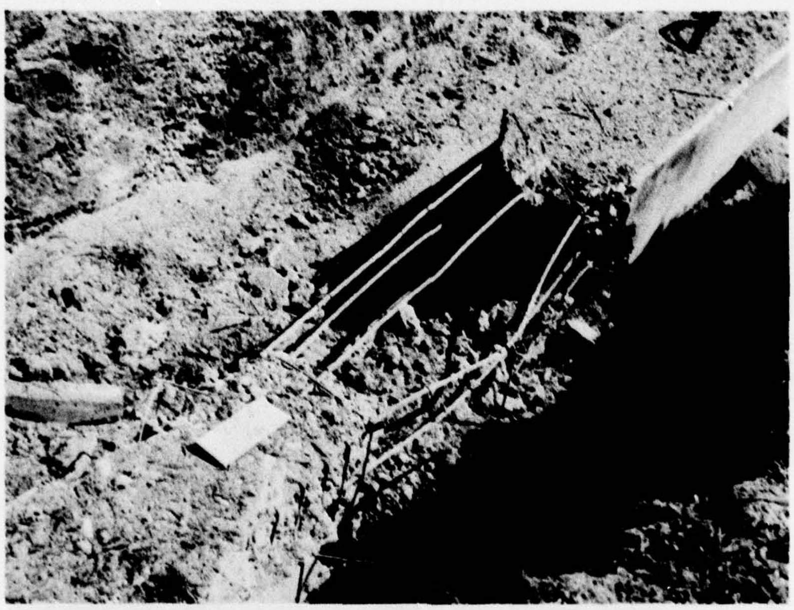
Figure 3.12 Test Series I, postshot structural steel sections, Tests 29 and 30.

a. Preshot view.

b. Postshot view.

Figure 3.13 Test Series II, Test 1.

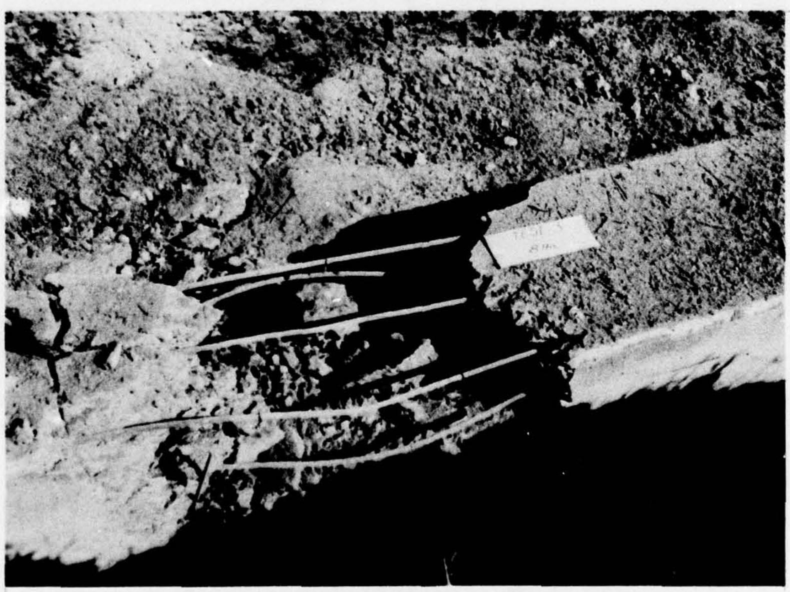
a. Preshot view.



b. Postshot view.

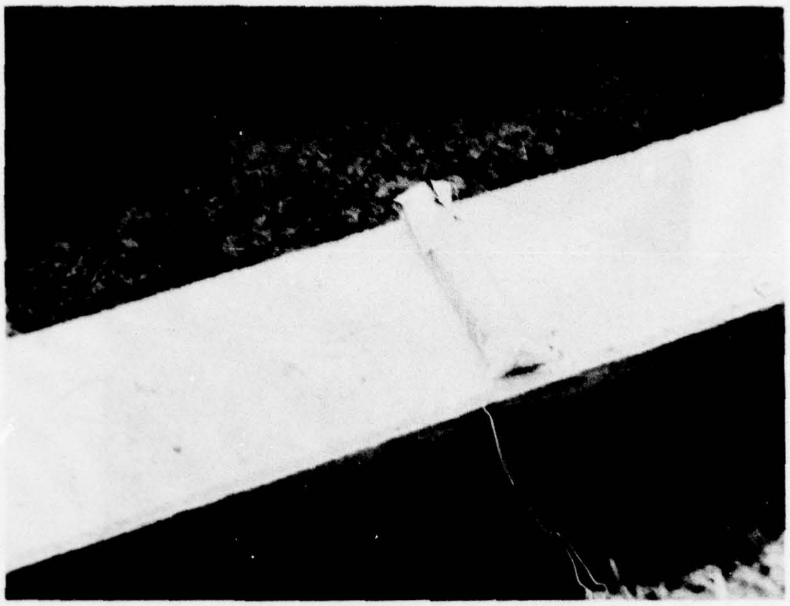
Figure 3.14 Test Series II, Test 2.

a. Preshot view.

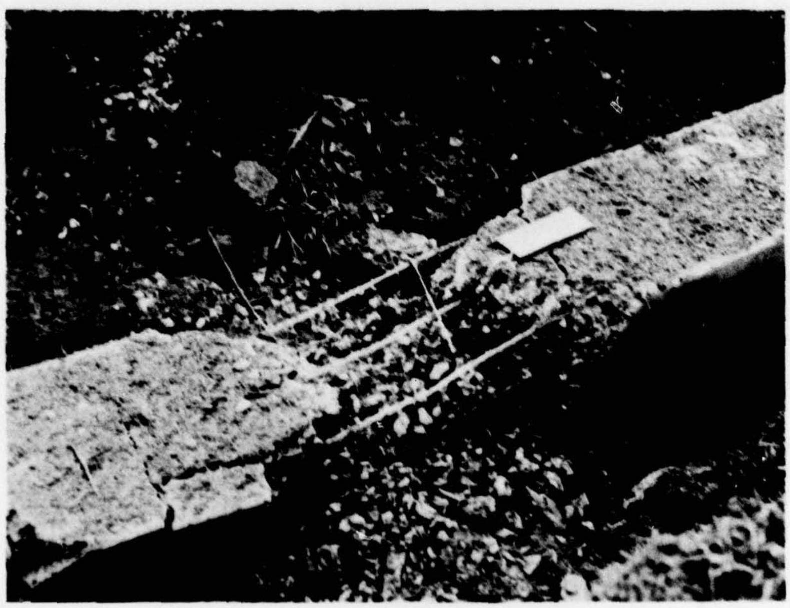


b. Postshot view.

Figure 3.15 Test Series II, Test 3.



a. Preshot view.



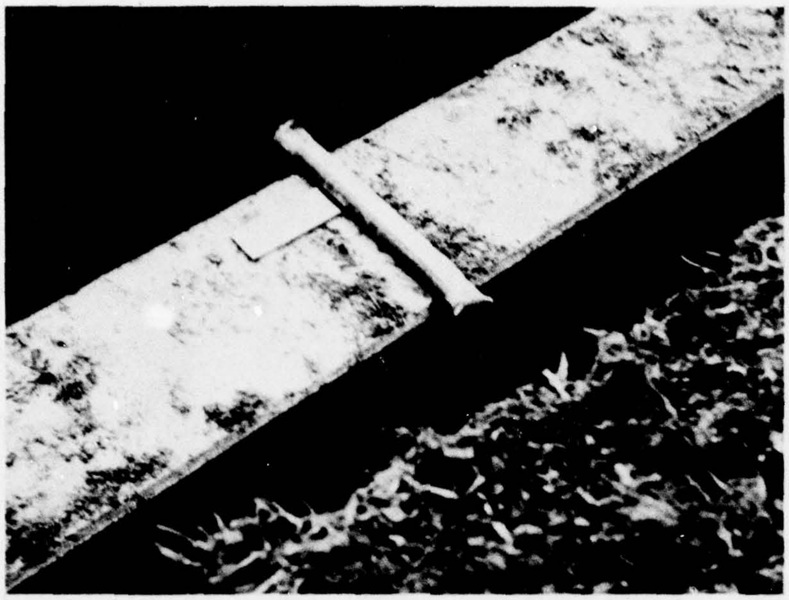
b. Postshot view.

Figure 3.16 Test Series II, Test 4.

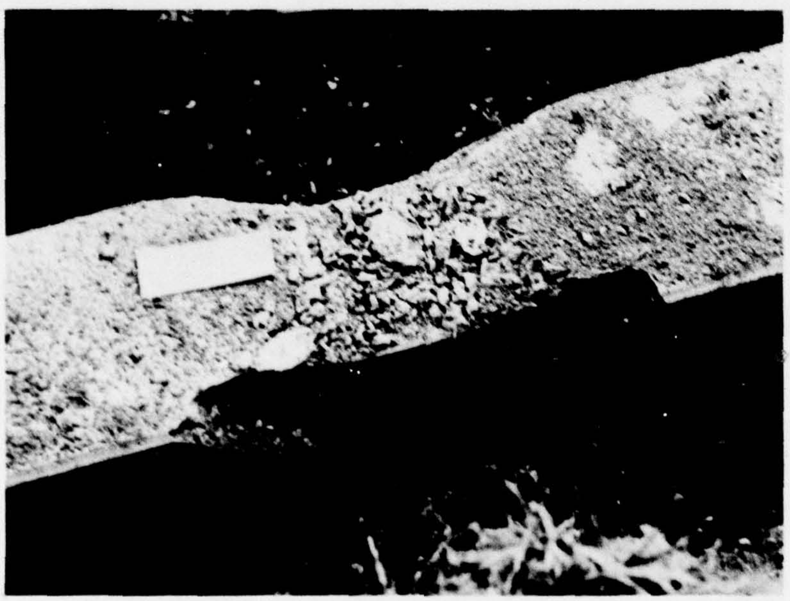
a. Preshot view.

b. Postshot view.

Figure 3.17 Test Series II, Test 5.



a. Preshot view.



b. Postshot view.

Figure 3.18 Test Series II, Test 6.

a. Preshot view.

b. Postshot view.

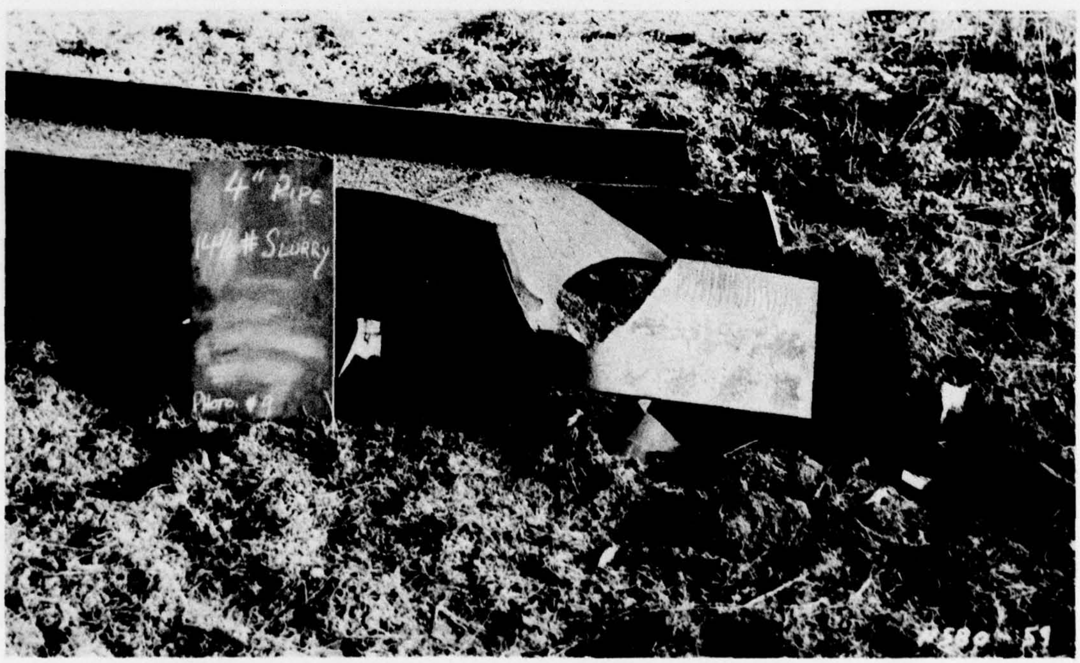
Figure 3.19 Test Series III, Test 1.

a. Preshot view.

b. Postshot view.

Figure 3.20 Test Series III, Test 2.

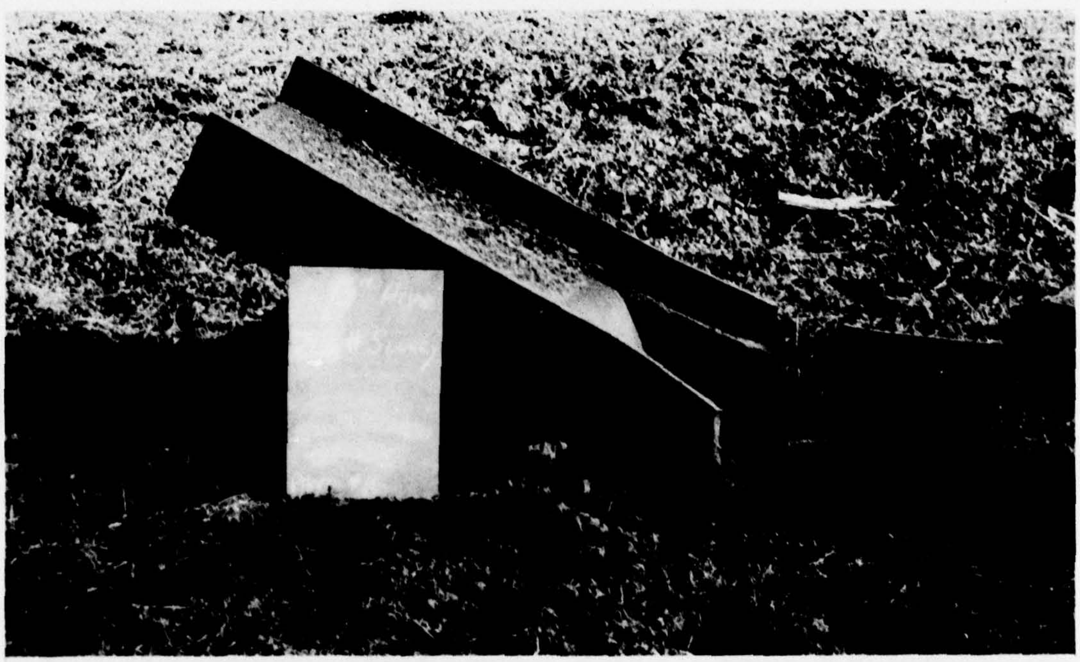
a. Preshot view.



b. Postshot view.

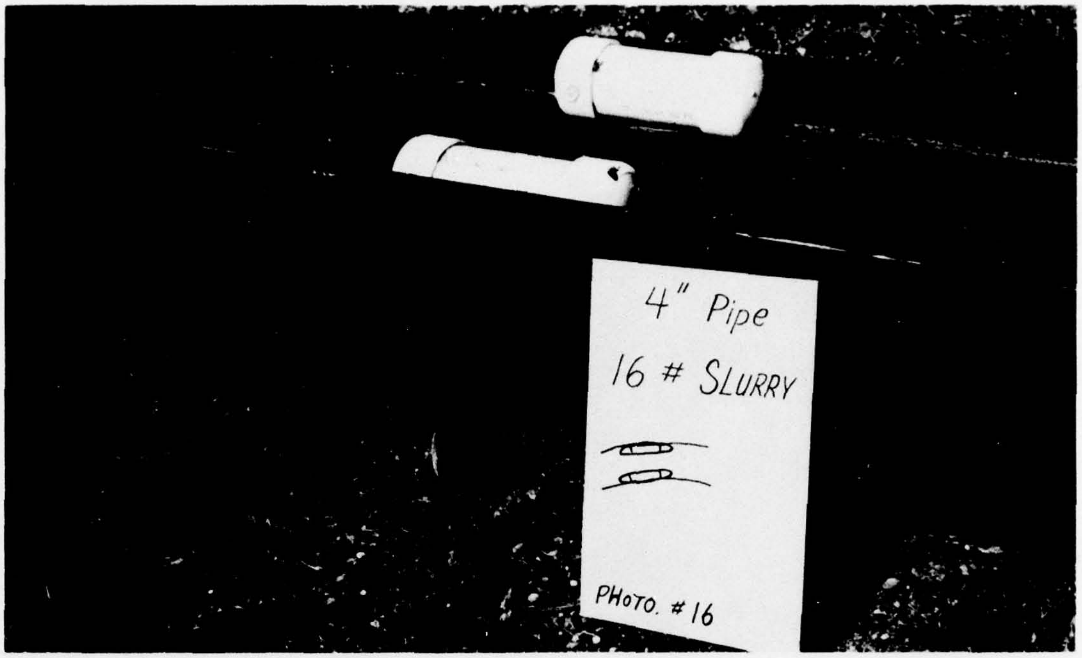
Figure 3.21 Test Series III, Test 4.

a. Preshot view.

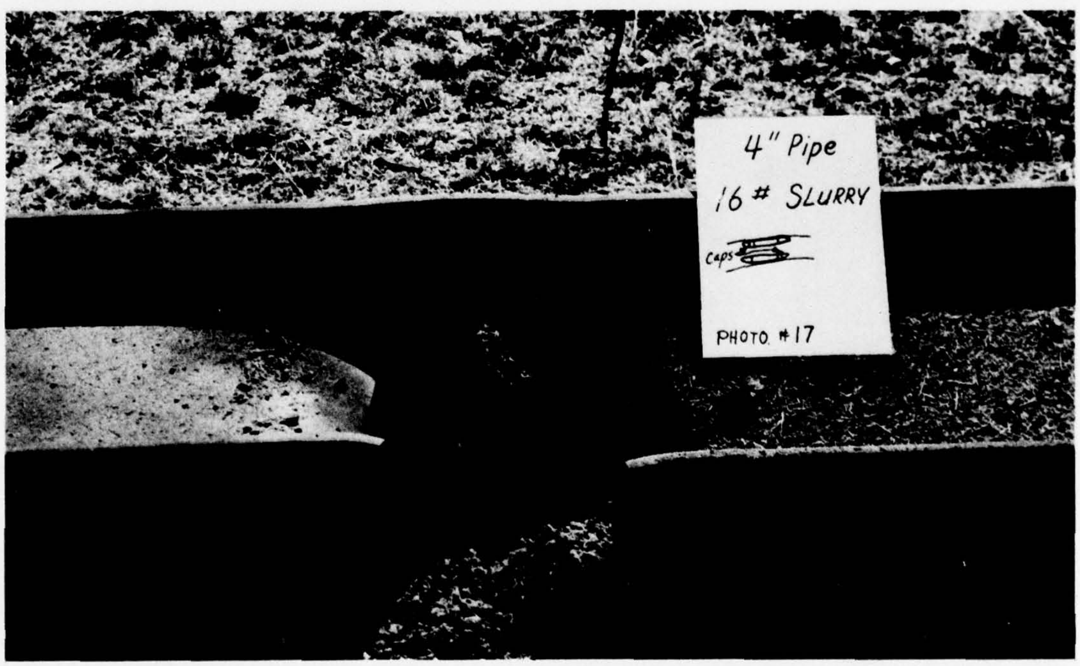


b. Postshot view.

Figure 3.22 Test Series III, Test 5.



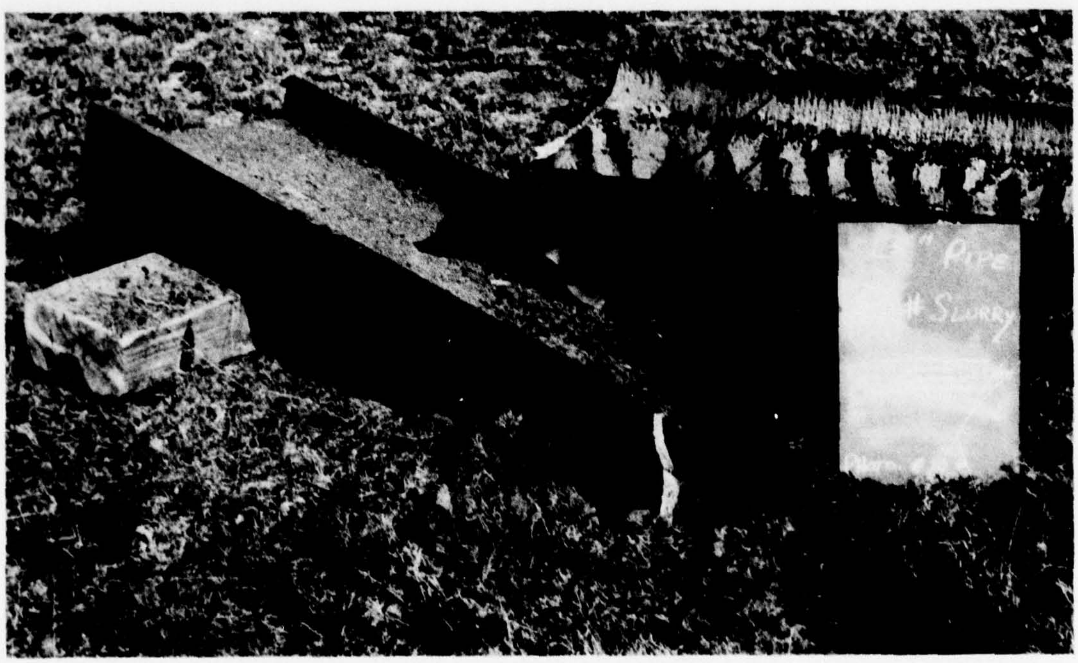
a. Preshot view.



b. Postshot view.

Figure 3.23 Test Series III, Test 6.

a. Preshot view.



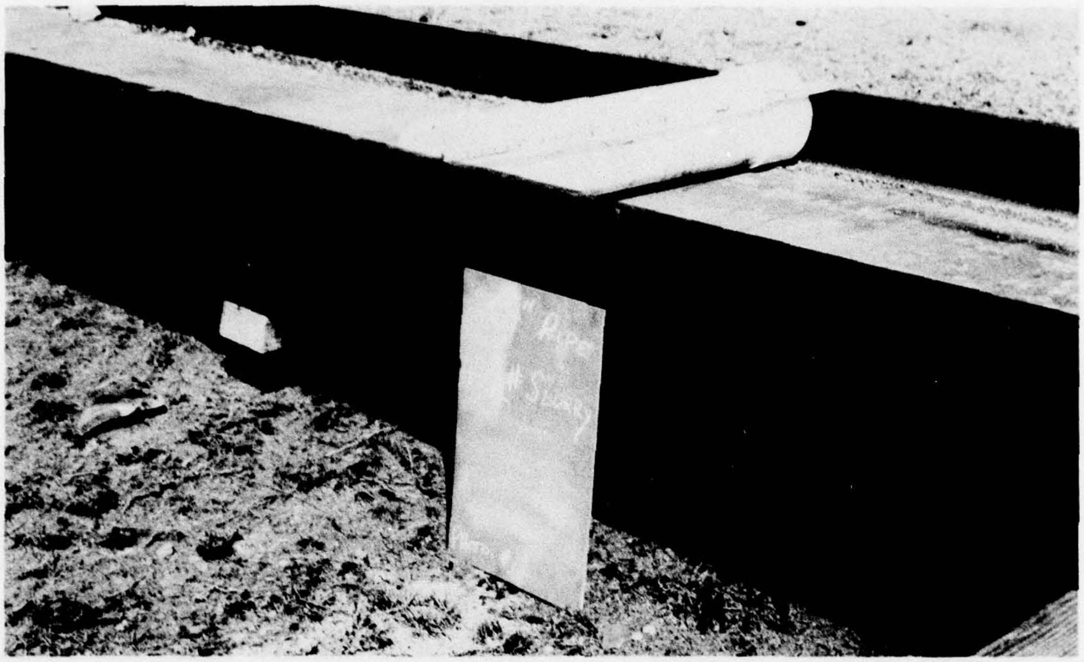
b. Postshot view.

Figure 3.24 Test Series III, Test 7.

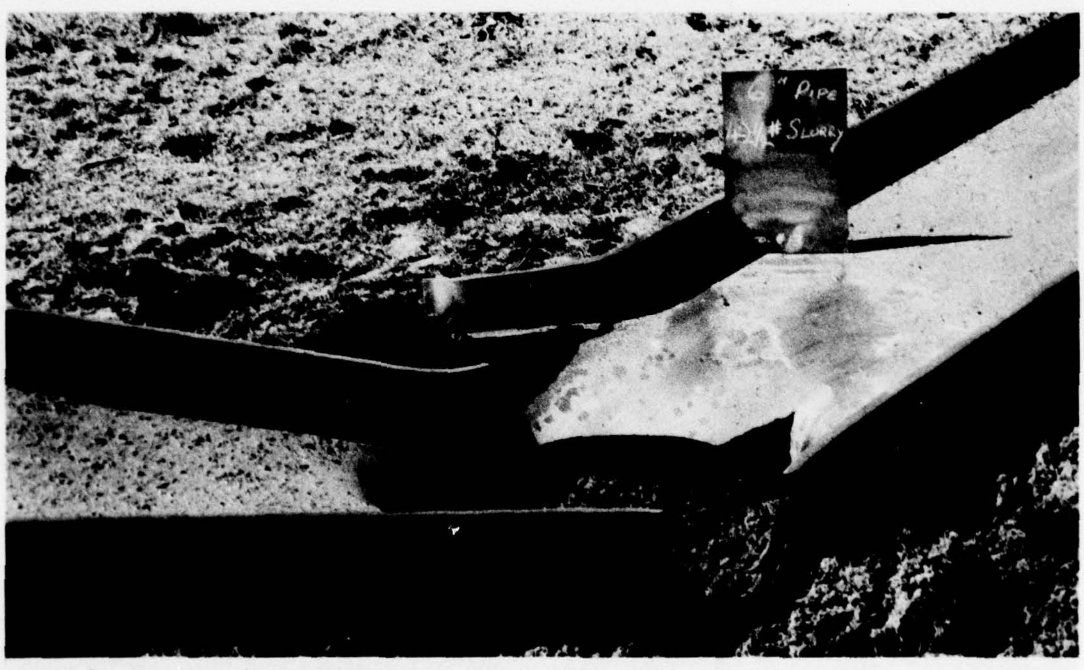
a. Preshot view.

b. Postshot view.

Figure 3.25 Test Series III, Test 8.



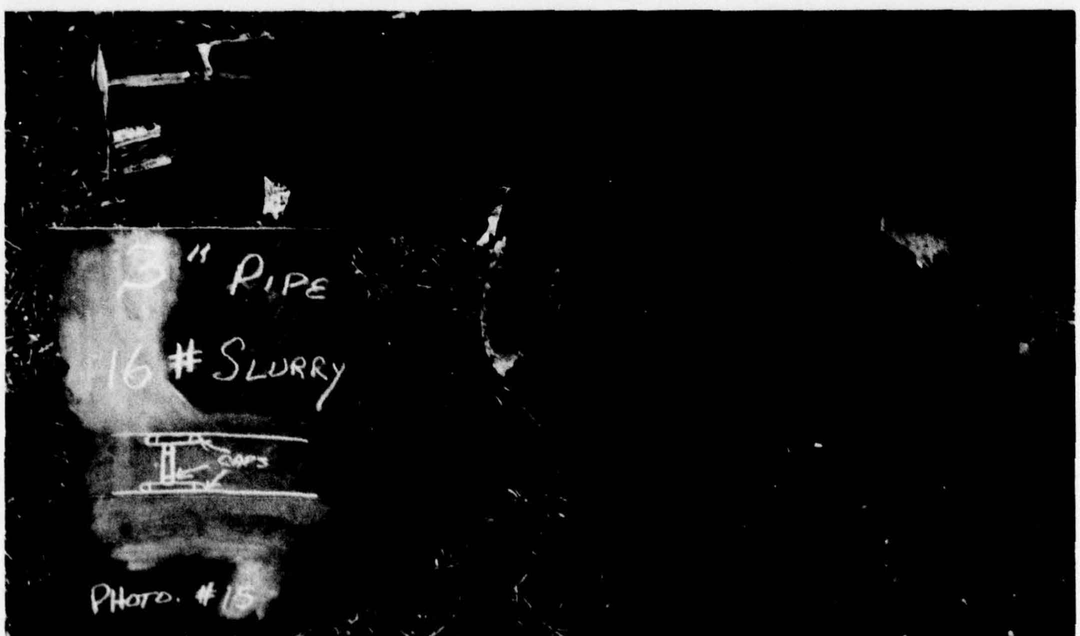
a. Preshot view.



b. Postshot view.

Figure 3.26 Test Series III, Test 9.

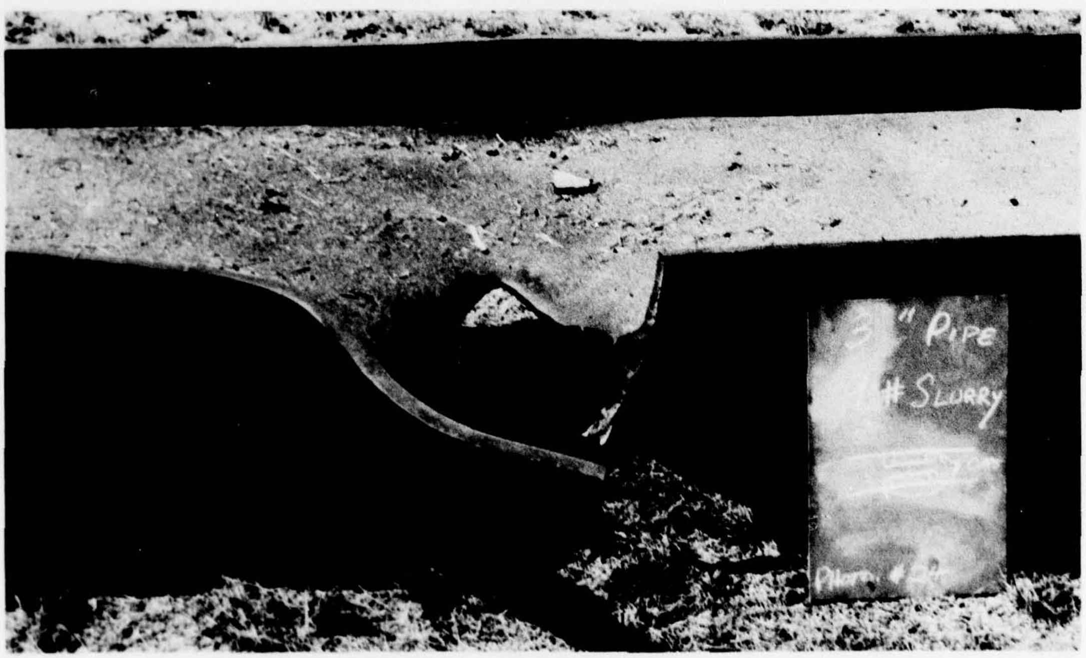
a. Preshot view.



b. Postshot view.

Figure 3.27 Test Series III, Test 10.

a. Preshot view.



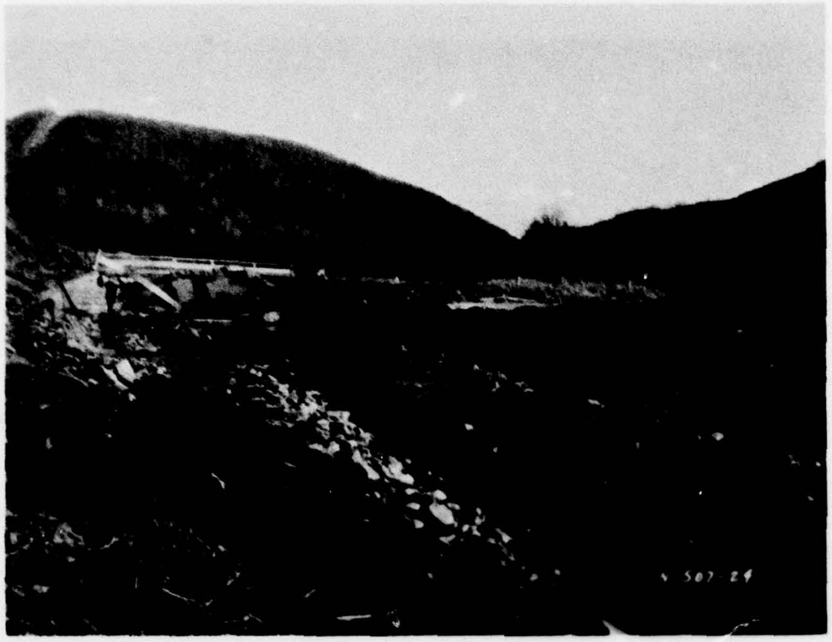
b. Postshot view.

Figure 3.28 Test Series III, Test 11.

a. Preshot view.

b. Postshot view.

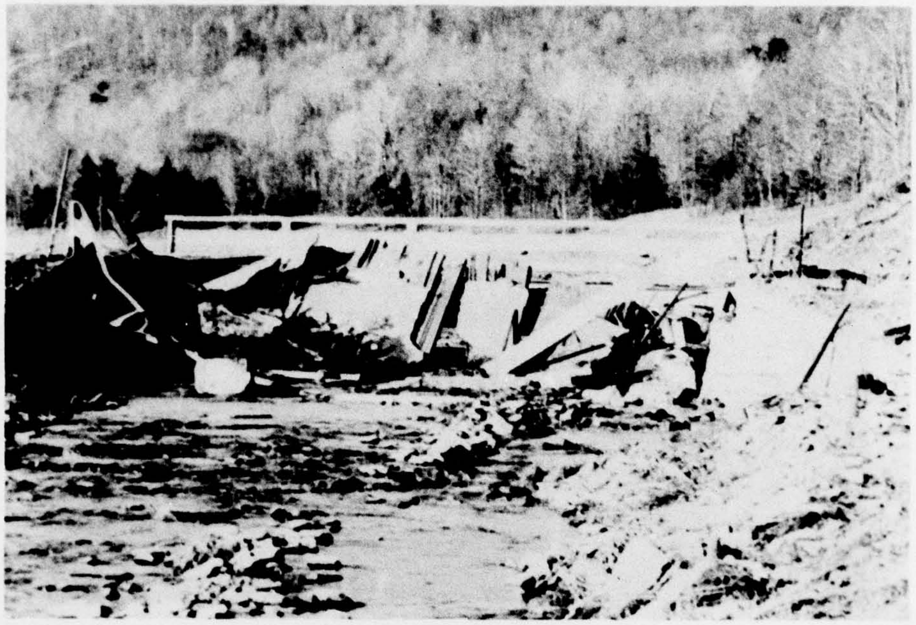
Figure 3.29 Test Series III, Test 12.



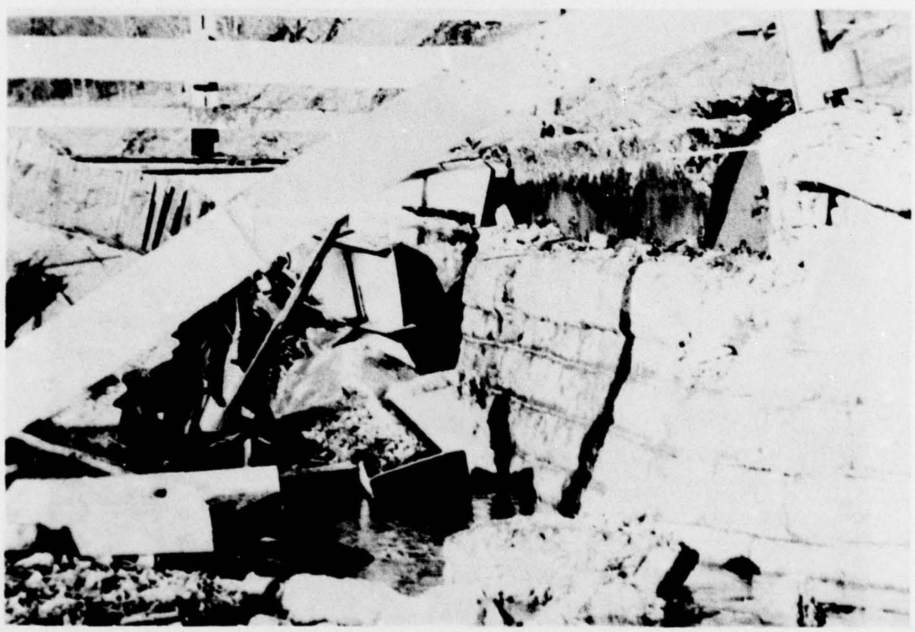
a. General view.

b. Left abutment.

Figure 3.30 Postshot view of Tatmen Run Bridge (sheet 1 of 3).



c. General view close-up.



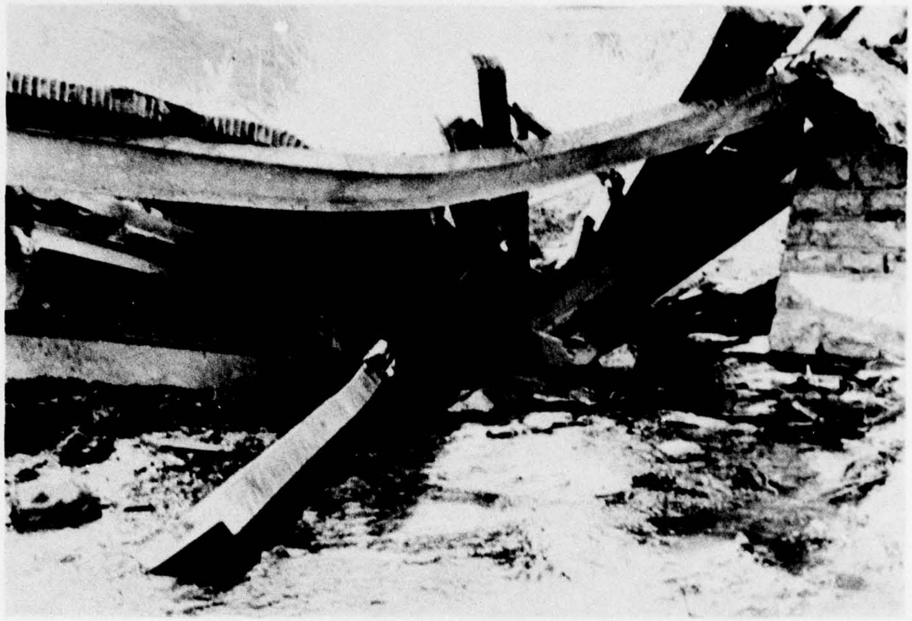
d. Right abutment.

Figure 3.30 (sheet 2 of 3).

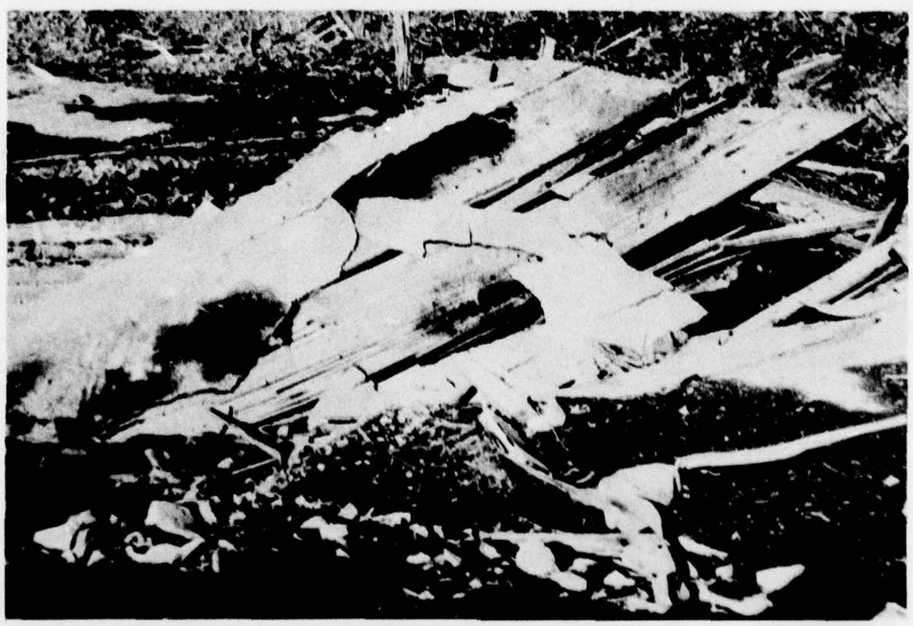
e. General view of steel beam displacement from bridge.

f. Twisted condition of bridge beams.

Figure 3.30 (sheet 3 of 3).



a. Side view of bridge damage.



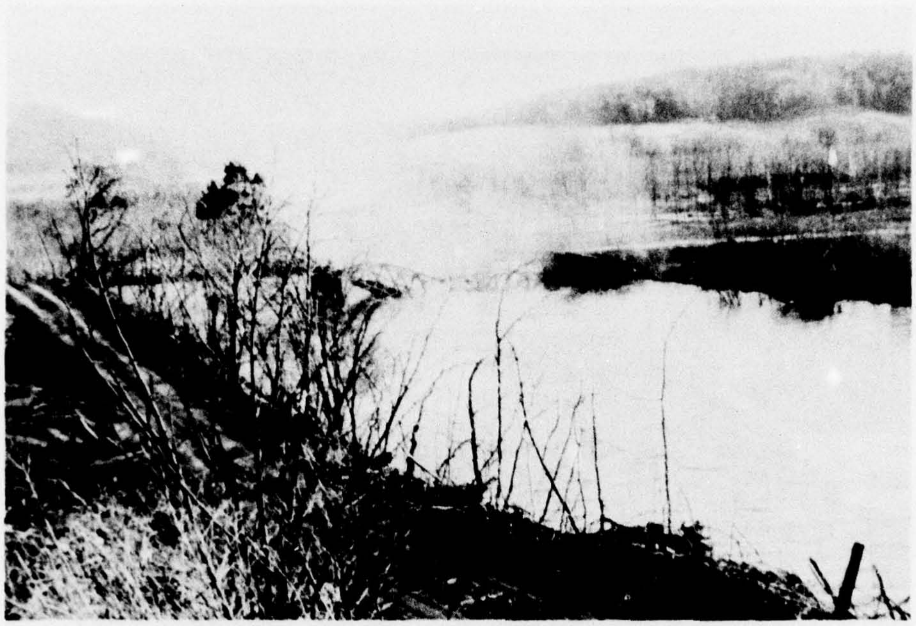
b. View of top side of bridge.

Figure 3.31 Postshot view of Coffee Run Bridge.

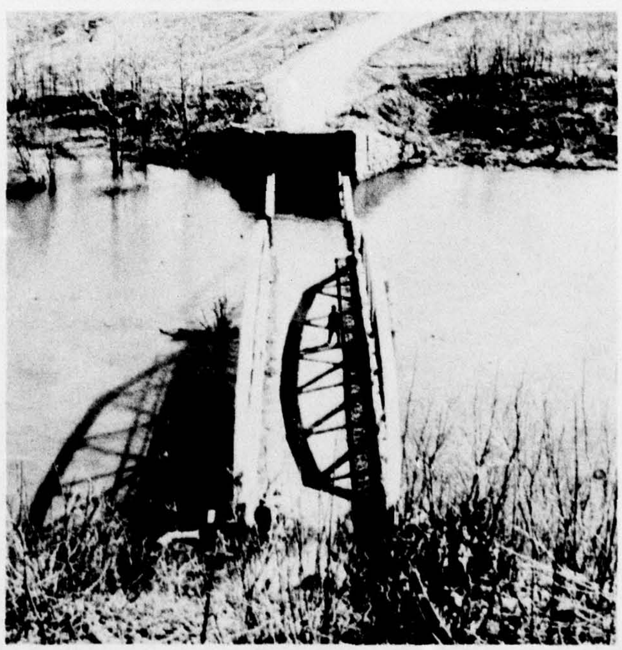
a. Collapsed bridge viewed from abutment.

b. Collapsed bridge viewed from stream bed.

Figure 3.32 Postshot view of Sayer's Bridge.



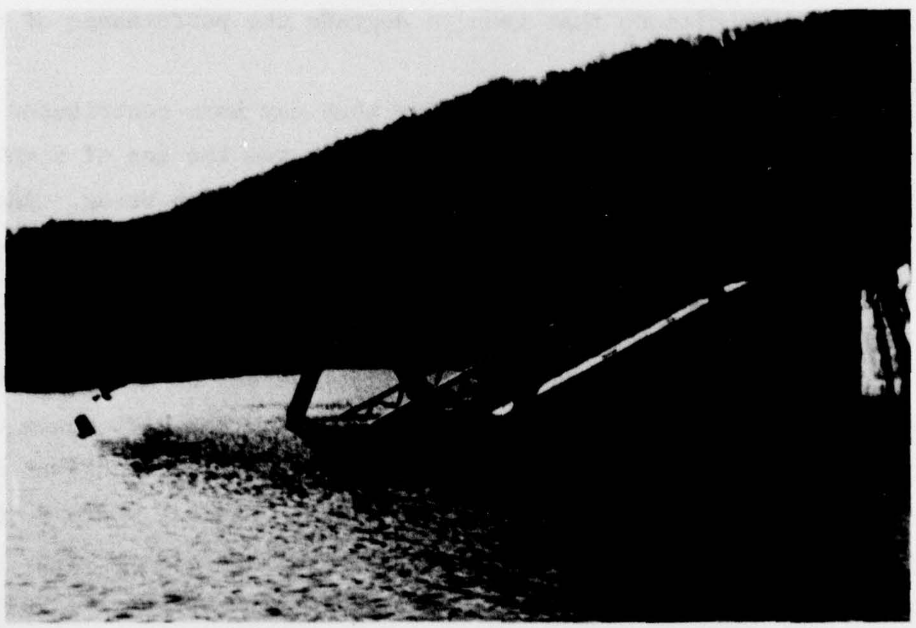
a. General view.



b. Overhead view along centerline of bridge.

Figure 3.33 Postshot view of Trexler Bridge
(sheet 1 of 2).

c. Damage of compression member.



d. Bridge end remained on center pier and slab deck slid into water.

Figure 3.33 (sheet 2 of 2).

CHAPTER 4

DISCUSSION OF RESULTS

4.1 STRUCTURAL ELEMENT TESTS

The literature[1,2] indicates that a high-order detonation, i.e., a detonation in the slurry which reaches and sustains a maximum steady-state shock-wave propagation, is highly dependent on proper boosting of the slurry. In Test Series I, attempts were made to minimize the booster with the idea that it was the effect of the slurry that was to be identified and, hence, a minimum spherical-shaped booster would best achieve this end. A second consideration was to identify how small a booster would initiate detonation of the slurry. A box-shaped container was used for convenience of placing and varying the total weight of slurry. These three conditions imposed on the slurry charge design--minimum booster, spherical booster shape, and the box-shaped slurry container--are conditions that tend to degrade the performance of the slurry.

Another condition in the test setup that may have contributed to the inability of the slurry to break the plate was the use of simply-supported plates. The plate tended to fold rather than break. Additionally, the 25 variables that affect the slurry's performance are influential in small total weights of slurry used during this test series. Test data accumulated represents a lower bound in the performance of the slurry and, hence, of its effectiveness on a steel plate. However, the test data were plotted (Figure 4.1). The plot shows that a curve formed by FM 5-25 formula $P = 3/8A$ plus a constant offset of 6 pounds is required to ensure damage to the steel plates, where P equals the pounds of TNT and A equals the area of steel to be destroyed. Charge and test configuration were improved for the Series III tests.

The PVC pipe container provided a certain degree of confinement to

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[1] "Monsanto Blasting Products ANFO Manual," op. cit.
[2] Dick, "Factors in Selecting and Applying Commercial Explosives and Blasting Agents," op. cit.

the slurry, and booster sizes were increased to 1/3 or 1/2 pound and placed in the slurry at the end of the container. The C-4 booster material was formed into a circular wafer. The intent of this arrangement was to impart to the slurry a shock wave as uniform and flat as possible. These charge configuration changes should have improved the explosive performance of the slurry. The 12-, 24-, and 36-inch-deep beams were not fixed at their support; but the massive weight of the beams provided considerable improvement over the simply-supported plates.

Recognizing the increased complication that results from the employment of multiple charge firings in close proximity to one another, the slurry charges were placed in the most efficient positions on the beam. The single charge placed on the web of a beam was never effective in removing both flanges. Therefore, the double charges placed at the intersection of the web and flange gave the best results. This arrangement made the explosive more evenly balanced with respect to the steel area it was to destroy.

Tests 3, 7, and 12, shown in Table 3.3, indicate breakage of the W12 × 50, W24 × 94, and W36 × 194 beams with slurry weights of 4.5, 9, and 16 pounds, respectively. Use of the $P = 3/8A$ formula of FM 5-25 yields respective TNT weights of 5.4, 10.1, and 20.9 pounds.

From Series I and III, very poor and very favorable effectiveness factors for slurry have been identified. This comparison is a very significant demonstration of the correct and incorrect way to apply a slurry blasting agent.

Test Series I and II contained tests on reinforced-concrete piers 12 by 12 inches and 16 by 16 inches in cross section. Test 34 of Table 3.1 and Test 3 of Table 3.2 indicate 3.3 pounds of slurry for the 12- by 12-inch section and 8.0 pounds of slurry for the 16- by 16-inch section, respectively. These cross sections of reinforced concrete were not large enough to establish the effectiveness of slurry by use of the breaching radius formula of FM 5-25. The concrete and oak wood member tests demonstrated that the slurry was effective in destroying these materials. The slurry appeared to work exceptionally well when applied to the concrete members.

4.2 PROTOTYPE BRIDGES

The demolition of the prototype bridges was conducted concurrently with the tests of structural elements; hence, charge designs on the various bridges were concerned more with the operational aspects of the problem rather than the amount of explosive used. For this reason and because of the lack of charge design criteria, the bridges were overcharged with explosives.

However, the placement of charges--i.e., slurry in the plastic bags as on the steel girder Tatmen Run Bridge and the steel truss Trexler Bridge, and slurry in prebuilt troughs--demonstrated the relative ease of using slurry in demolition operations. The time involved in rigging the bridges with the slurry explosive was comparable to the time involved when any other explosive is employed. A reduction in the time to charge the bridges was observed and is attributable to the fact that little attention was needed to care for details because more charge weight than needed was used. This type of time advantage would be applicable to any other explosive material used under the same circumstances.

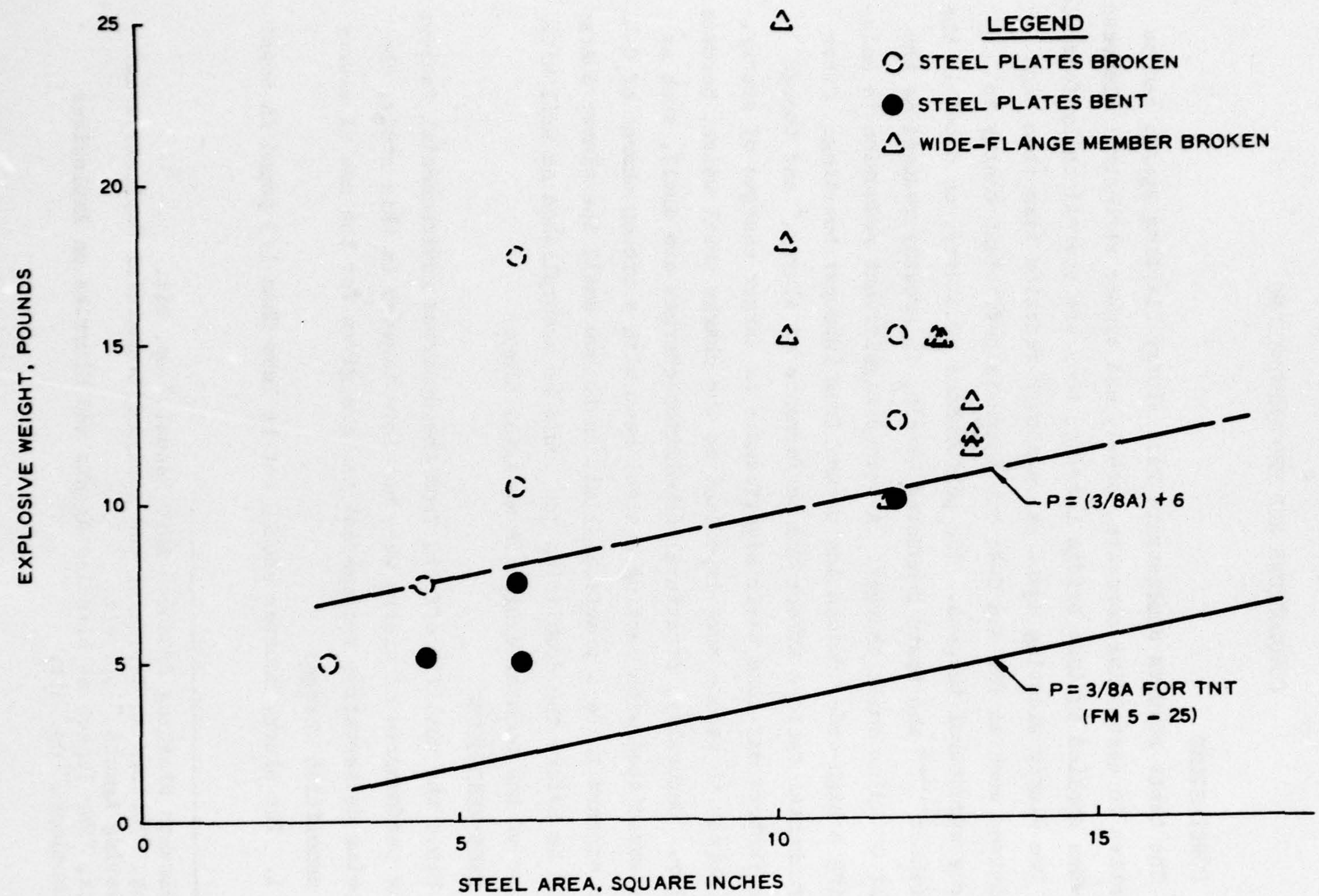

Figure 4.1 Weight of slurry explosive versus steel area.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The tests results demonstrate that slurry blasting agents can be effective in destroying concrete, steel, and timber structural elements; and when applied against bridge targets, they are operationally feasible.

The slurry blasting agent has a slower reaction time than high explosives such as TNT and C-4; but there is sufficient energy to destroy structural targets. The performance of slurry, as noted in the references[1,2,3] and tests conducted herein, is greatly reduced as the result of using small charges. A second significant reduction in maintaining a high-order detonation occurs from improper boosting. Other environmental factors affect the performance of slurry,[1] and though these factors may lose their significance in larger charges of slurry, they appear to become more important as the charge total weight becomes smaller. Generally, structural demolition charges are small, such as those associated with cutting a steel beam with a ribbon charge of C-4. There appears to be a practical limit as to how small the slurry charge should be before the demolition job could be accomplished as well with the use of the booster explosive material alone.

5.2 RECOMMENDATIONS

Since the specific effects from the numerous environmental factors on the performance of slurry were not investigated in this study, the following conservative recommendations are given for the use of slurry as a demolition charge:

1. The slurry booster should not be less than 1/3 pound in total

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[1] "Monsanto Blasting Products ANFO Manual," op. cit.

[2] Dick, "Factors in Selecting and Applying Commercial Explosives and Blasting Agents," op. cit.

[3] Dick, "The Impact of Blasting Agents and Slurries on Explosives Technology," op. cit.

weight of high explosive, i.e., TNT, C-4, or the commercially available precast slurry boosters.

2. The booster should be placed in intimate contact with the slurry blasting agent and the booster should be shaped as a flat wafer to ensure that a large flat shock wave enters the slurry charge.

3. Figure 4.1 indicates, and it is recommended, that a minimum weight of 6 pounds be used in conjunction with the formula of FM 5-25 ($P = 3/8A + 6$) for cutting steel elements.

4. Additional testing is recommended to verify the use of the demolition formula contained in FM 5-25. The addition of six more pounds of slurry to the weight determined by the appropriate formula in FM 5-25 should produce a reasonable charge design.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Watt, James M
Development of engineering criteria for use of slurry-type explosives against tactical structural targets / by James M. Watt, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
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